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Zooplankton Community Composition in Natural and Artificial Estuarine Passes of Lake Pontchartrain, Louisiana

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Zooplankton Community Composition in Natural and Artificial Estuarine Passes of Lake Pontchartrain, Louisiana

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Dedication

I dedicate this manuscript to my wife, Katie Kerisit, and my two girls, Elise and Amelie. Thank you for your love, support, and patience.

Acknowledgments

I would like to thank my advisor Dr. Martin O'Connell for giving me the opportunity to work in his lab and all the support he has given me throughout this process. I would also like to thank my committee members Dr. Ioannis Georgiou and Dr. Frank Hernandez for offering their advice and time. I appreciate the help of Chris Schieble, Angela Williamson, Iain Kelly, Maiada Bader, Dr. Patrick Smith, Geoff Udoff, Dr. William Stein, Rebecca Cope, and Damon Morse. I would like to thank Dr. Michael Poirrier and Claire Caputo for helping me with specimens' identification. Angela Denniston, you have done a remarkable job helping me in the lab. I will always be thankful for your help. I would also like to thank Mike (OGO) and Dianne (belle-maman) for their encouragement and support throughout this long process. Lastly, this would have not been possible without my little tribe. Katie, Elise et Amélie, merci du fond du coeur, je vous aime tres fort.

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Abstract

I assessed the composition of zooplankton communities at the three tidal inlets connecting Lake Pontchartrain to Lake Borgne and subsequently to the Gulf of Mexico. The objectives of my research were to better understand the factors contributing to both spatial and temporal differences in zooplankton communities at the three locations. Monthly samplings of the neuston were conducted from September 2009 until April 2011 and then again from September 2012 until May 2013. Sampling consisted of triplicate tows using SeaGear "Bongo" nets. Water quality data along with water turbidity were recorded at each site and during each sampling effort. All specimens collected during the survey were quantified and identified to the lowest taxonomical unit. The results indicated that there were significant differences among the aquatic invertebrate communities composition among the three sites groups averaged across months (ANOSIM, R= 0.162, p = 0.001). The outcomes from this study could have strong implications for fisheries management and will provide a baseline for future research.

Keywords: Zooplankton communities, *Rhithropanopeus harrisii*, zoea, tidal inlets, Lake Pontchartrain, Louisiana, Gulf of Mexico

Chapter 1

Introduction

Estuarine-dependent invertebrate life history strategies

"The bipartite life history of most estuarine-dependent invertebrates generally results in a decoupling of presettlement forms from spawning adults and the environment occupied by adults" (Kingford M. J., et al., 2002). Consequently, numerous estuarine-dependent crustaceans produce planktonic larvae that exhibit three patterns of development: the expelled estuarine life-history pattern, the external estuarine life-history pattern and the retained life-history pattern (Queiroga *et al*., 1997; Hasek and Rabalais, 2001; Almeida and Queiroga, 2003).

In the expelled estuarine life-history pattern, planktonic larvae released inside the estuary undergo development in the water over the continental shelf for periods of weeks to months before recruiting back to the adult population in the estuary (Shanks *et al*., 2000). The Blue Crab (*Callinectes sapidus*), one of 14 species of *Callinectes*, utilizes such a life-history pattern. This particular species of portunid crab has a range extending from Canada to northern Argentina and was introduced to parts of Europe (Millikin and Williams, 1984). One of the most ecologically and commercially important species in the Western Atlantic and the Gulf of Mexico, *C. sapidus* live as adults in estuaries, in contrast to their larvae (zoea) which are released by ovigerous females on the edge of estuaries to be subsequently transported to offshore coastal water (Heck *et al*., 2001). The numbers of days necessary to go through the seven to eight larval stages varies from 35 to 60 days. Variability in abiotic factors, such as temperature and salinity, will dictate the amount of time and the number of zoeal stages needed before the postlarvae recruits back to the estuary (McConaugha, 1992).

In the external life-history pattern, spawning occurs in coastal waters. The planktonic larvae undergo ontogenetic development as they migrate into the estuary. The Brown Shrimp (*Farfantepenaeus aztecus*), the prevailing species caught in the shrimp industry in the United States, uses such a life-history pattern (Li and Clarke, 2005). The distribution of *F. aztecus* ranges from New Jersey to Florida and throughout the Gulf of Mexico (Cook and Lindner, 1967). This species spawns on the Gulf of Mexico continental shelf throughout the year with peak activity from September through November (Li and Clarke, 2005). The demersal eggs hatch within 24 hours, and the planktonic larvae develop offshore through five naupliar, three proto-zoeal, and three mysis stages. The postlarvae recruit back to the estuary during the winter and spring with a peak in late February through March (Larson *et al*., 1989; Li and Clarke, 2005).

In the retained estuarine life-history pattern planktonic larvae have a shorter larval development in comparison to the expelled and external estuarine life-history planktonic larvae. Swimming behavior displayed by planktonic larvae such as vertical migration during tidal cycles allows for the retention of the larvae close to the adult population (Cronin and Forward, 1983; Hasek and Rabalais, 2001). The estuarine Mud Crab (*Rhithropanopeus harrisii*) ranges along the eastern coast of North and Central America. Also known as the Harris Mud Crab, *R. harrisii* has also been introduced to Europe and was recently discovered in Japan (Forward and Richard, 2009). This xanthid crab species passes through four zoeal stages followed by a postlarval stage or megalopal stage (Lambert and Epifanio, 1982). The zoeas are retained in the estuary by altering their vertical positioning in the water column (Cronin, 1983). Zoeas ascend in the water column during flood tide and descend during ebb tide to avoid being flushed out the estuary (Forward and Richard, 2009).

Cross-shelf transport mechanisms

For many estuarine-dependent species successful recruitment involves migration of adults out of an estuary and the subsequent larval transport back to the estuary (Hench *et al*., 2004). Larval recruitment to the estuary of estuarine species with a dispersive larval phase has been described as a two-step process. Firstly, larvae have to be transported over the shelf, and secondly, they have to pass through inlets and move up-estuary to settle in a suitable habitat (Queiroga *et al*., 2006). Physical processes, both coastal oceanographic and meteorological, significantly influence the estuarine-dependent organisms' early life-history stages (Blanton *et al*., 1999). A number of studies conducted over the past 50 years in various geographical parts of the world have permitted researchers to identify different physical processes taking place at varying spatial scales and temporal scales (Sponaugle *et al*., 2002). Additionally, dispersion mechanisms of larvae away from the estuary and recruitment mechanisms of postlarvae or juvenile back to the estuary across the shelf differ from the mechanism taking place within the estuary because of variance in environmental conditions and in topographical areas (Almeida and Queiroga, 2003).

Wind-driven surface currents induced by wind forcing have been proposed as a mechanism for both the dispersion onto the continental shelf of *C. sapidus* larvae and the recruitment back to the Chesapeake Bay of the postlarvae. The results of a study suggested that this mechanism was advantageous for the dispersion of larvae away from the Bay but not a significant one for the recruitment of megalopae (Johnson, 1995). Similarly, a study conducted off the coast of northern Portugal suggested that temporal fluctuation of megalopae of the European Common Shore Crab (*Carcinus maenas*) was caused by wind-driven circulation. The study showed that *C. maenas* megalopae recruitment to the Ria de Aveiro was correlated to wind stress (Almeida and Queiroga, 2003). The role of tidal wind-generated currents in transporting White Shrimp (*Litopenaeus setiferus*) postlarvae was assessed in another study conducted near the North Edisto estuary, South Carolina. The results of this study indicated that downwelling favorable winds with an onshore component facilitated the transport of *L. setiferus* postlarvae into the estuary (Wenner *et al*., 1998).

In the southeastern United States, cold fronts are the prevailing weather pattern from October to April. They usually occur at an interval of four to seven days and propagate from north-west to south-east (Chuang and Wiseman, 1983). The orientations of the frontal passages are particularly important along the northern coast of the Gulf of Mexico which lies mainly in the East-West direction. Cold fronts, which last from 25 to 45 hours, can generate severe water level changes. A strong cold front can flush more than 40% of the water contained in bays onto the continental shelf (Feng and Li, 2010). Associated with these frontal passages are pre-frontal winds from the southern quadrant. The southerly winds promote onshore water movement for up to 10 h prior to the passage of the front. This is important for winter offshore spawning fishes such as Atlantic Croaker (*Micropogonias undulatus*), Spot (*Leiostomus xanthurus*), and Gulf Menhaden (*Brevoortia patronus*) because it provides a possible mechanism for transporting larvae back to the estuary (Johnson and Allen, 2005)

Internal waves are produced by the mixing of coastal water by tidal currents. Internal waves propagate shoreward as non-linear internal waves or internal bores (Shanks, 2006). Internal wave phenomena have been proposed as a transport mechanism for neustonic larvae (surface dwelling) and water column larvae which occur between the bottom and the surface (Pineda, 1994). At low wind speed internal waves become apparent at the surface in the form of wide slicks. The manifestation of the internal waves at the surface is associated with the accumulation of debris and planktonic organisms. The current generated over the waves causes convergence at the wave trough and divergence at the wave crest, thus explaining the accumulation of both material and organisms (Shanks, 1983; Lennert-Cody and Franks, 1999). In a field experiment, the surface slick potential for onshore transport was tested using free-running drogues placed on either side of surface slicks. The first trials were inconclusive. There was no shoreward movement by the free running drogues. The concentration of invertebrate larvae in the surface slicks was not significantly different than the one between the surface slicks. Subsequent trials yielded dramatically different results. There was a significant shoreward movement and the concentrations of larvae of invertebrates in the slicks were for some species 200 times greater than in between the slicks. These results underlined the potential for shoreward transport of neustonic larvae by surface slicks associated with internal waves (Shanks, 1983).

Aquatic invertebrates' behavioral response to physical and chemical cues

Successful recruitment and settlement phases of marine organisms are highly dependent on their capabilities to sense their environment and alter their behavior accordingly. Marine invertebrates and fish species have senses that allow them to detect variation in the surrounding aquatic environment. Numerous organisms are capable of detecting changes in water chemistry, sound and vibration, light gradient, current direction and water pressure (Kingford *et al*., 2002). These physical and biological cues can provide information to species on the distance to their natal habitat. The different ontogenetic stages of marine invertebrates and fishes are likely to influence their capability to sense physical and biological cues due to physiological constraint associated with their developmental stage. Consequently, marine organisms are likely to respond differently to a number of stimuli associated with the occupied environment at specific times throughout their life cycle. An extensive number of field and laboratory experiments regarding behavioral response of aquatic invertebrates and fishes to chemical and physical cues have been conducted. For example, *C. sapidus* was shown to exhibit behavioral responses to flow, chemical and visual cues (Diaz *et al*., 2003; Fig. 1). Also, *Scylla serrata* (a portunid crab found in the Indo-Pacific region) displayed enhanced swimming activities when subjected to variations in light regime (Webley and Connolly, 2007). Additionally, the behavioral responses of *R. harrisii* and *Neopanope sayi* larvae to changes in water temperature were such that both brachyuran crab larvae exhibited upward swimming movement when the temperature decreased and a downward swimming movement when the temperature increased (Forward and Richard, 1990). Thus, physical and biological cues likely play an important role in the successful recruitment and settlement phases of marine invertebrates and fish species.

Cue	Effect on metamorphosis	Source
Water type		
Offshore	Delay	Wolcott & De Vries (1994), Forward et al. (1994), (1996), Brumbaugh & McConaugha (1995), this study
Estuarine	Accelerate	Forward et al. (1994), (1996), this study
River	Accelerate	This study
Estuarine chemical cues		
Humic acids	Accelerate	This study
Ammonium chloride	Delay	This study
Salinity decrease	Accelerate	Forward et al. (1994), Wolcott & De Vries (1994)
Aquatic vegetation		
Seagrasses		
Zostera marina	Accelerate	Forward et al. (1996)
Halodule wrightii	Accelerate	Forward et al. (1996)
Ruppia maritima	Accelerate	Forward et al. (1996)
Macroalgae		
Ulva lactuca	Accelerate	Brumbaugh & McConaugha (1995)
Ulva rotundata	Accelerate	Forward et al. (1996)
Bryopsis plumosa	Accelerate	Forward et al. (1996)
Enteromorpha sp.	No effect	Forward et al. (1996)
Hypnea musciformis	Accelerate	Forward et al. (1996)
Gracilaria sp.	No effect	Brumbaugh & McConaugha (1995)
Scyphosiphon lomentaria	No effect	Forward et al. (1996)
Sargassum natans	No effect	Forward et al. (1996)
Saltmarsh cord grass		
Spartina alterniflora	Accelerate	Forward et al. (1996)
Substrate		
Clean oyster shells	No effect	Forward et al. (1996)
Plastic rods, ribbon	No effect	Forward et al. (1996)
Glass rods	No effect	Forward et al. (1996)

Figure 1. List of cues with potential to affect *C. sapidus* metamorphosis (Forward, *et al., 1997*)

Site description and background

Pontchartrain Basin

The Lake Pontchartrain Basin, which occurs partially in Southeast Louisiana, is one of the most diverse and imperiled ecosystems in the Gulf of Mexico. It covers a surface area of 24,980 km^2 (Lopez, 2009; Fig. 2). The upland drainage basin extends north into Mississippi. The western and eastern boundaries are provided by the Mississippi River human-made levees and the Pearl River watershed, respectively. The southern boundary is the Gulf of Mexico. The Pontchartrain Basin drains almost 13,000 km^2 of diverse and unique woodland and wetlands through 16 parishes in Louisiana and 4 counties in Mississippi (Reed, 2009; EPA map; Fig. 2). The basin contains five major rivers (Amite, Tickfaw, Tangipahoa, Tchefuncte and Pearl) that drain southward into three major lakes. To the west the Amite and Tickfaw rivers drain into Lake Maurepas. In the center the Tangipahoa and Tchefuncte Rivers drain into Lake Pontchartrain. To the east the Pearl River watershed drains into Lake Borgne. The Pearl River drainage measures 18,400 km^2, and the Amite, Tickfaw, Tangipahoa, and Tchefuncte Rivers, combined, drain an estimated surface area of 10,700 km^2 (Sikora and Kjerfve, 1985).

Figure 2. Map of the Greater and lower Lake Pontchartrain Basin (Lopez, 2009).

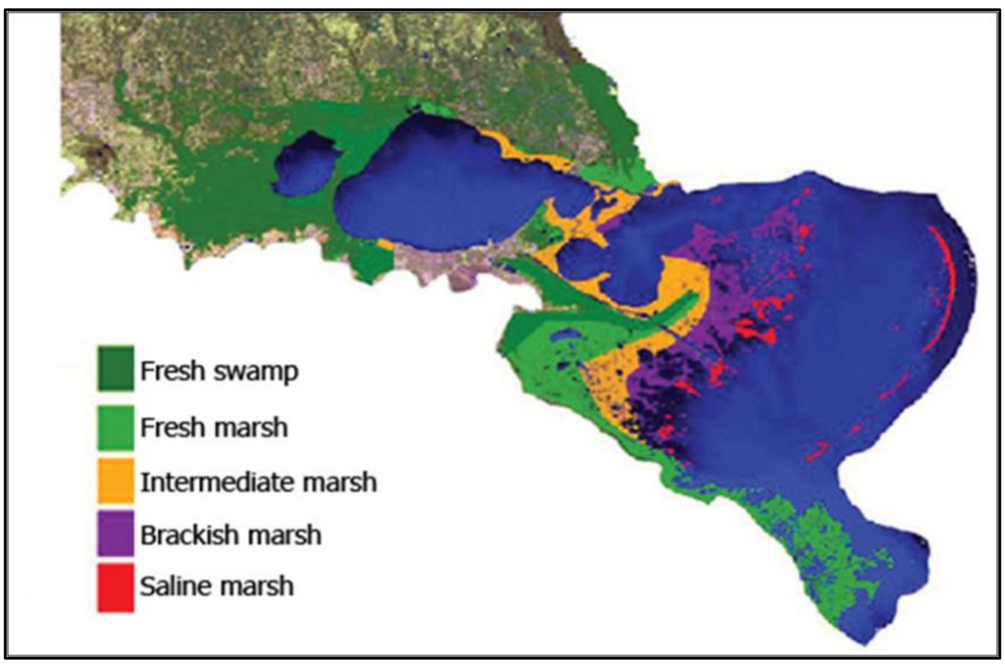


Figure 3. Type of marshes along the Pontchartrain basin (Dardis & Pendarvis, 2010)

The Pontchartrain Estuary makes up the southern portion of the basin. The surface area of the three major estuarine water bodies (Lake Maurepas, Lake Pontchartrain and Lake Borgne) is 8,000 km^2 (Flocks *et al*., 2009). Three natural tidal inlets and a human-made navigational waterway connect the three estuarine lakes together. To the west, Lake Maurepas is connected to Lake Pontchartrain by Pass Manchac. To the east, two natural tidal inlets, the Rigolets Pass and Chef Menteur Pass, connect Lake Pontchartrain to Lake Borgne. To the south, the Inner Harbor Navigation Canal (IHNC) connects Lake Pontchartrain to the Intracoastal Waterway (ICWW) and, subsequently, to the Mississippi River Gulf Outlet (MRGO).

Lake Pontchartrain

Lake Pontchartrain is situated at the center of the basin. It is the largest of the three major estuarine water bodies with a surface area of 1630 km^2 and an average depth of 3.7 m (Sikora and Kjerfve, 1985). The distance on an east-west axis is 60 km, and 40 km on a north-south axis. The depth generally decreases on an east-west transect while depth increases on a south-north transect. The tidal amplitude ranges from 3 to 45 cm (McCorquodale and Georgiou, 2004). Water movement within the Lake is primarily induced by wind forcing. Water movement in the three tidal inlets is dominated by tidal forcing. The tidal exchange through the passes is 7800 m^3/s. The Rigolets Pass accounts for 64% of the tidal exchange whereas Chef Menteur Pass and the IHNC account for 30% and 6% of the tidal exchange respectively (Haralampides, 2000). The Lake is classified as being oligohaline, having a low salinity regime varying from 1 to the west to 6 to the east (McCorquodale *et al*., 2009)

Freshwater input is the main factor controlling the salinity regime of Lake Pontchartrain. The Amite River watershed, which comprises the Amite, Blind, and Tickfaw Rivers, is the principal source for freshwater input into Lake Pontchartrain. Although urban runoff of storm water only accounts for a fraction of the total freshwater input in the Lake, a rise in urbanization on the Northshore could have the effect of increasing freshwater input into the Lake (Sikora and Kjerfve, 1985). Direct rainfall on the Lake surface is also a non-negligible source of freshwater. The Pontchartrain Estuary is subjected to a subtropical climate which results in a significant amount of precipitation during the warmer months. The Bonnet Carre Spillway (BCS) situated in the southwestern corner of Lake Pontchartrain is another potential source of freshwater. The structure, made up of 350 floodgates, was constructed from 1929 to 1936. Its role is to divert water from the Mississippi River into the lake when the levee system bordering the city of New Orleans could be compromised by flood waters. The BCS was opened eleven times between its date of completion in 1936 and 2016. The most recent opening occurred in 2016, and the maximum water discharge recorded was 5748 m^3/s (Army Corp Of Engineers website 2016).

Saltwater influx, in the Lake, is relatively limited when compared to freshwater input. The size of the tidal passes and the small tidal fluctuation prevent major salinity increases (McCorquodale *et al*., 2009). Furthermore, the Pearl River flowing to the east of the Rigolets Pass prevents higher salinity water originating from the Gulf of Mexico to enter Lake Pontchartrain (Sikora and Kjerfve, 1985). Among the three tidal passes connecting Lake Pontchartrain to Lake Borgne, the MRGO, prior to its closure in 2009, allowed higher salinity water to enter the southeastern part of the Lake via the mouth of the IHNC. The construction of the MRGO by the U.S. Army Corps of Engineers (USACE) was completed in 1963. This deep-draft shipping channel has an average depth of 11 m and measures 120 km (Sikora and Kjerfve, 1985). The projected increase in salinity caused by the transport of saltwater from Breton Sound via the MRGO and into the lake was predicted to be between 4.3 to 5.5 (Sikora and Kjerfve, 1985). Although, the overall salinity in Lake Pontchartrain did not increase as predicted, the high salinity water entering the lake at the mouth of the IHNC caused the water column to stratify. Subsequently, detrimental hypoxic and anoxic events became common in the vicinity of the IHNC (Shaffer *et al*., 2009). Stochastic meteorological events such as tropical storms or hurricanes are the only events that have the potential to drastically increase the salinity regime. For example, during Hurricane Gustav the salinity increased from 3 to 20 at the Industrial Canal and from 3 to 25 at the Rigolets (Li *et al*., 2009)

Lake Pontchartrain ecological environment

Lake Pontchartrain is an important ecological and economical asset to southeastern Louisiana. The Lake is used for various activities, including boating, swimming, and fishing. It also supports an important Blue Crab fishery. Furthermore, the Lake provides critical habitat for estuarine-dependent species. Numerous fish species (*B. patronus, Cynoscion nebulosus, and M. undulatus)* and crustacean species (*C. sapidus, L. setiferus, and P. aztecus)* utilize the unique and abundant resources and habitats produced by the Lake.

Unfortunately, Lake Pontchartrain has been subjected to various detrimental anthropogenic effects over the course of almost three centuries (Lopez, 2009). The development of urban centers on both the Southshore (New Orleans) and the Northshore (Covington, Mandeville, Lacombe, and Slidell) has negatively impacted water quality throughout the Lake. The analysis of a long-term dataset showed that demersal fish assemblages in Lake Pontchartrain have been negatively impacted due to the effect of human disturbances (O'Connell *et al*., 2004). Microbial contamination of the Lake waters after rain events, particularly at Lincoln Beach and by the Jahnckle Canal, was elevated enough to be a concern to human health (Jin *et al*., 2004).

In 1997, the opening of the BCS was associated with a subsequent drop in salinity, a cyanobacteria bloom, and the presence of an anoxic and hypoxic zone. Consequently, a decrease in benthic species diversity was observed (Brammer *et al*., 2007). The MRGO, as described previously, allowed for higher salinity water to enter the Lake via the IHNC. This saltwater wedge resulted in the stratification of the water column over a 250 km^2 area. The resulting anoxic and hypoxic zone has had a detrimental impact on the sessile benthic community and more particularly on the ecologically dominant clam species *Rangia cuneata* (Poirrier *et al*., 2009). The decline of R. *cuneata* populations cannot be attributed to just one factor (i.e., saltwater intrusion via IHNC) but rather to a combination of factors. For decades, *R. cuneata* were dredged from the Lake to be used as an alternative to gravel in driveways. A ban was passed in 1991, and the dredging operation in the Lake was ended (Lopez, 2009). Additionally, the armoring of parts of the Southshore, to prevent shore erosion, had detrimental effects on the Submersed Aquatic Vegetation (SAV). Successful SAV settlement was inhibited due to an increase in wave energy level and water turbidity (Cho and Poirrier, 2005; Cho and Poirrier, 2005). Thus, the main anthropogenic activities that have led to the modification of the Lake ecosystem are well understood. Significant science based restoration efforts should be put in place to mitigate those effects, in order to preserve this ecologically and economically important ecosystem.

Current Study

The present study is in continuation of a previous project started by graduate student Rebecca Cope. Field sampling started in February 2008 and ended in May 2013. The objectives of the first project were the following: 1) to determine the impact of the closure of the MRGO on the assemblages of juvenile and adult fishes in Lake Pontchartrain; 2) to assess changes in larval fish assemblages at the tidal inlets; and 3) to assess changes in water quality following the closure of the MRGO. The dataset used for the first project included the time period from February 2008 to December 2010. The focus of my study was on investigating the factors influencing the composition of aquatic invertebrate communities at the three tidal inlets (Rigolets Pass, Chef Menteur Pass and the IHNC). The data set I used was from the time period from September 2009 until May 2013. It is important to point out that the sampling effort was interrupted for a period of sixteen months from April 2011 to September 2012. Due to some overlapping in the dataset used in both studies, the collection method used in the field was similar for consistency.

My main objective was to better understand the abiotic factors affecting the composition of aquatic invertebrate communities at the three tidal inlets. More precisely, my objectives were the following:

1) To determine any compositional differences in aquatic invertebrate communities throughout the year at the three tidal inlets,
2) To assess the various physical forcing events (e.g., tidal forcing, wind forcing) affecting the composition of the aquatic invertebrate communities, and
3) To determine how various abiotic factors (e.g., water temperature, salinity and turbidity level) affect the composition of the aquatic invertebrate communities.

Materials & Methods

Collection Methods

Plankton tows were performed at three sites: Rigolets Pass and Chef Menteur Pass in Pass in Lake Pontchartrain, and in the IHNC at Seabrook (Fig. 4, 5, 6).

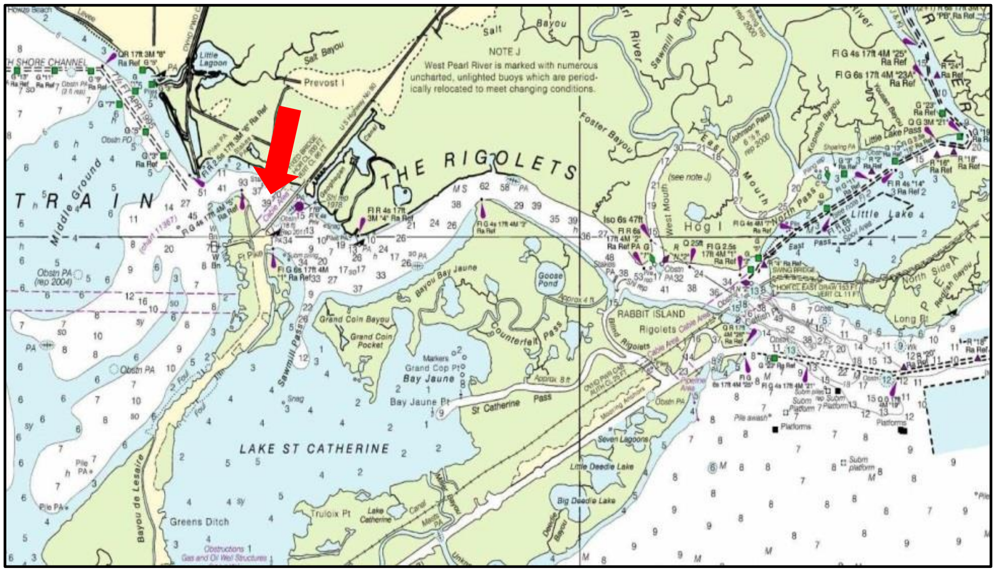


Figure 4. Map showing the sampling location at the Rigolets Pass.

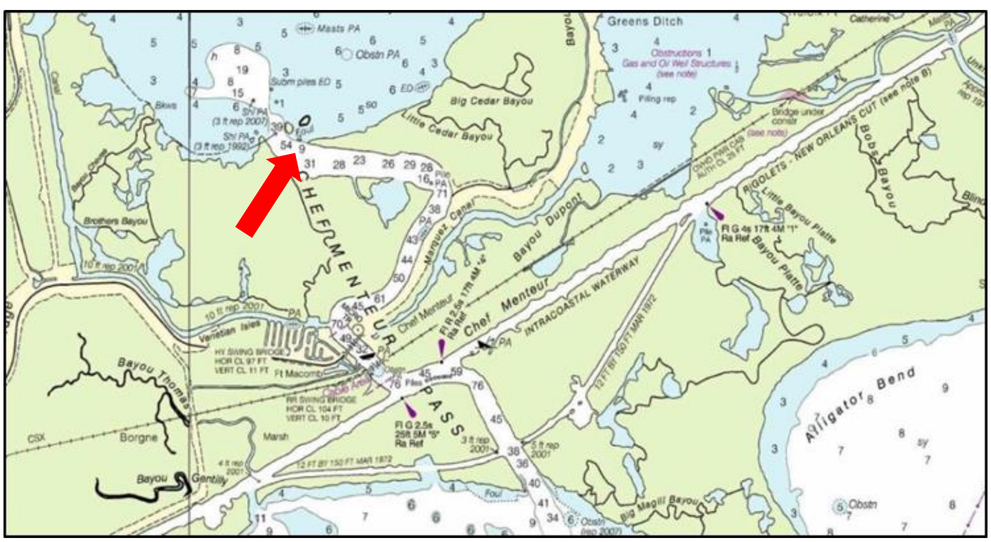


Figure 5. Map showing the sampling location at the Chef Menteur Pass.

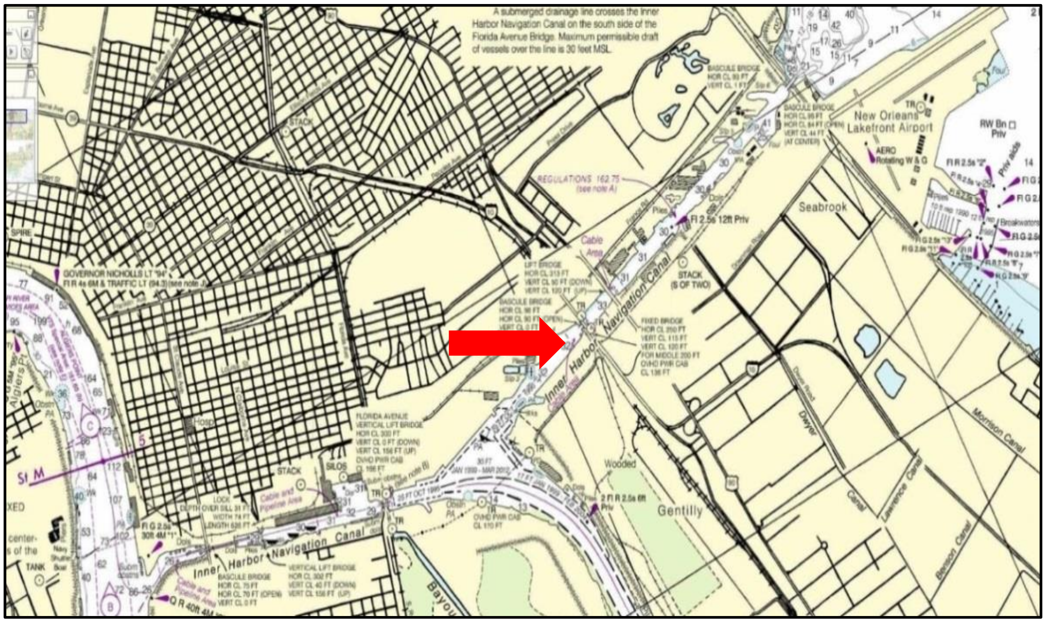


Figure 6. Map showing the sampling location the Inner Harbor Navigational Canal (IHNC).

Plankton tows were performed during the strongest flowing tide period of the month. The tows were completed in triplicate, with three SeaGear "Bongo" nets (500 µ mesh size, attached to 1 m diameter hoops) towed simultaneously at the water surface for ten minutes across the width of the pass (perpendicular to the incoming tide) in order to cover as much of the pass as possible (Fig. 7). Using a Yellow Springs Instruments meter (YSI model 85 SCT-DO meter), water quality data were collected for each site, including temperature (°C), salinity, dissolved oxygen (mg/L), and specific conductivity (S). Additionally, turbidity was assessed by measuring water clarity with a secchi disk. Collected samples were preserved on-board with 10% Rose Bengal-dyed buffered formalin solution. The samples were then processed in the laboratory, utilizing a 250 µ sieve and stored in a 70% ethanol solution. Samples were then sorted and identified taxonomically to the lowest level possible.

Figure 7. Images depicting the field collection methods.

Statistical Analyses

All biotic data were analyzed using the Plymouth Routines in Multivariate Ecological Research (Primer) version 6 statistical software package. The biotic data were standardized (average abundances per meter cubed) and square-root transformed to down weight the effect of the most common species. Non-metric multidimensional scaling (MDS) plots were constructed, based on a Bray-Curtis similarity matrix, to depict multi-dimensional relationships in a two dimensional graph. An MDS plot allows for the visual interpretation of assemblages similarity or dissimilarity. Assemblages that are more similar in species composition will appear closer together. Subsequently, a two way crossed analysis of similarity (ANOSIM; $p = 0.05$) was applied to test for significant differences among assemblages. The factors used were the sampling sites (Rigolets Pass, Chef Menteur Pass, and Seabrook) and months when sampling effort were conducted. The ANOSIM index, R, represents the similarity between compared samples and range from +1 and -1. The closer to 0 the R value is and the more similar the compared samples are in composition. Alternatively, an R value closer to 1 indicated that the compared samples are more different in composition. A negative R value means that the assemblages' compositions are more similar between them than within. Similarity percentage analysis (SIMPER) was then used to assess the contribution of each species to the observed similarity or dissimilarity between the samples. Finally, BIO-ENV was used to determine relationships among environmental data (water quality measurements) and invertebrate assemblage changes. The abiotic factors were normalized and the biotic data were not transformed as it was the case in the MDS, ANOSIM, and SIMPER analysis.

Results

Testing for compositional differences in aquatic invertebrate communities throughout the year at the three tidal inlets.

A total of 175,756 specimens, representing 15 different families, were collected during the study (Fig. 8). A total of 96,964 specimens were collected from Chef Menteur Pass. This represents 55.17% of the overall abundance. A total of 59,871 specimens were collected from the Rigolets Pass representing 34.06% of the overall abundance. Finally, a total of 18,921 specimens were collected from Seabrook representing 10.77% of the overall abundance. The most abundant species at the three sites was *R. harrisii* with 156,816 specimens collected representing 89.22% of the total combined species abundance. In comparison, the second most abundant group, although not identified to the species level in this study, were the larval fishes with 9,495 specimens collected representing 5.4% of the total combined species abundance. The primary contributor to dissimilarity at the three sites was *R.harrisii* which comprised 94.91% of the assemblage at Chef Menteur Pass, 79.56% at the Rigolets and 90.68% at Seabrook. The species which was the least abundant was *Lucifer faxoni*, a species of sergestid shrimp, with only one specimen collected at the Rigolets during the entire duration of the study. All other species were collected at the three sites with different levels of abundance (Table 1, 2, 3)

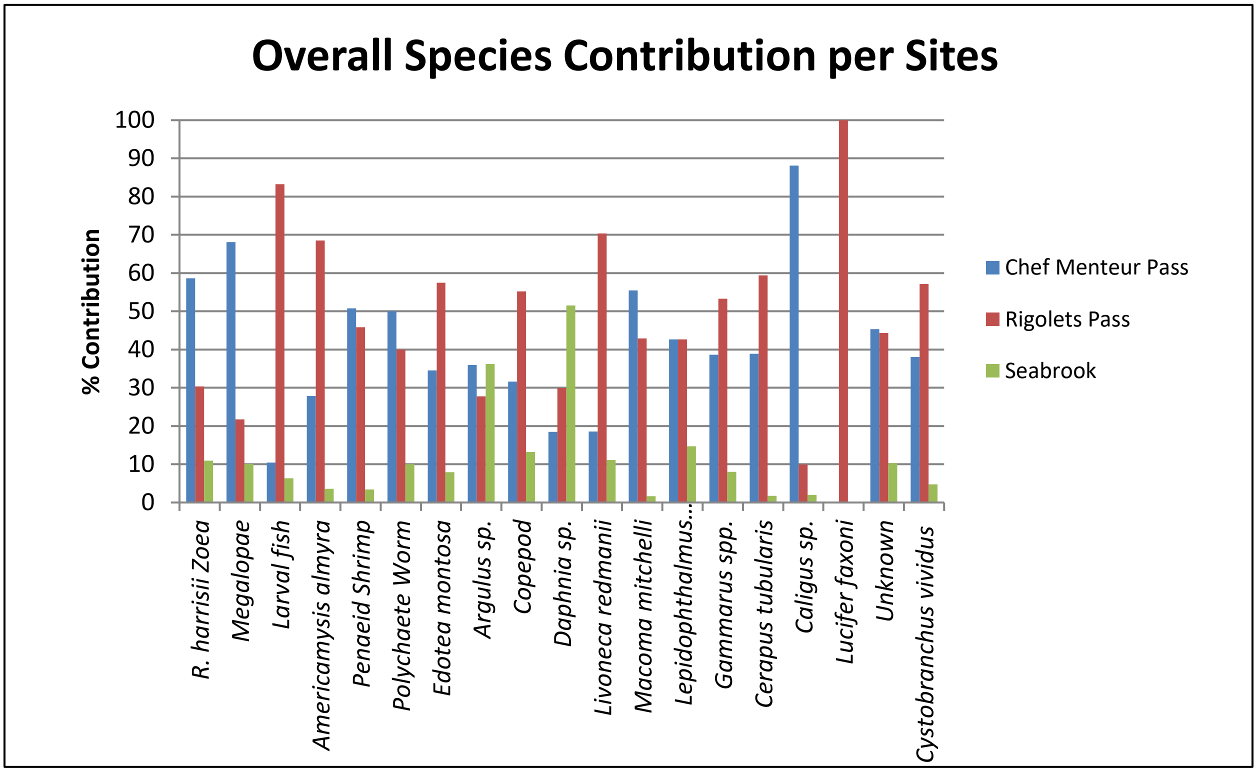


Figure 8. Graph representing the percent overall contribution of all species at the three sampling location.

Table 1. The following table summarizes the number of specimens of each species collected at and their overall percent contribution at Chef Menteur Pass.

Chef Menteur Pass		
Species	**# of Specimens**	**% Contribution**
Rhithropanopeus harrisii	92027	94.91
Larval Fish	992	1.02
Penaeid Shrimp	771	0.8
Argulus spp.	633	0.65
Macoma mitchelli	609	0.63
Gammarus spp.	529	0.55
Cerapus tubularis	523	0.54
Edotea montosa	231	0.24
Megalopae	169	0.17
Copepod	139	0.14
Americamysis almyra	108	0.11
Caligus spp	89	0.09
Daphnia spp	53	0.05
Unknown	44	0.05
Lepidophthalmus louisianensis	29	0.03
Cystobranchus vividus	8	0.01
Polychaete Worm	5	0.01
Livoneca redmanii	5	0.01
Lucifer faxoni	0	0

Table 2. The following table summarizes the number of specimens of each species collected and their overall percent contribution at Rigolets Pass.

Rigolets Pass		
Species	**# of Specimens**	**% Contribution**
Rhithropanopeus harrisii	47632	79.56
Larval Fish	7904	13.2
Cerapus tubularis	800	1.34
Gammarus spp.	729	1.22
Penaeid Shrimp	696	1.16
Argulus spp.	488	0.82
Macoma mitchelli	471	0.79
Edotea montosa	384	0.64
Americamysis almyra	266	0.44
Copepod	243	0.41
Daphnia spp	86	0.14
Megalopae	54	0.09
Unknown	43	0.07
Lepidophthalmus louisianensis	29	0.05
Livoneca redmanii	19	0.03
Cystobranchus vividus	12	0.02
***Caligus* spp**	10	0.02
Polychaete Worm	4	0.01
Lucifer faxoni	1	0

Table 3. The following table summarizes the number of specimens of each species collected and their overall percent contribution at Seabrook.

Seabrook		
Species	**# of Specimens**	**% Contribution**
Rhithropanopeus harrisii	17157	90.68
Argulus spp.	637	3.37
Larval Fish	599	3.17
Daphnia spp	148	0.78
Gammarus spp.	110	0.58
Copepod	58	0.31
Edotea montosa	53	0.28
Penaeid Shrimp	52	0.27
Megalopae	25	0.13
Cerapus tubularis	23	0.12
Macoma mitchelli	18	0.1
Americamysis almyra	14	0.07
Lepidophthalmus louisianensis	10	0.05
Unknown	10	0.05
Livoneca redmanii	3	0.02
Caligus spp	2	0.01
Polychaete Worm	1	0.01
Cystobranchus vividus	1	0.01
Lucifer faxoni	0	0

MDS

An MDS plot was created to spatially represent the relationship among the three sampling sites over the entire sampling effort period (September 2009-May 2013). Assemblages that have a similar species composition will appear to be closer together than the assemblages with a more dissimilar species composition. A total of five outliers were removed from the plot by creating two subsets of the original MDS. The samples removed had no specimens collected. This in return allowed for a better visual interpretation of the differences among the sites. The MDS visual rendering of the compositional differences in zooplankton communities among the three sites exhibit no discernable differences in the way the samples were distributed. The aquatic invertebrate communities at the Rigolets, Chef Menteur Pass, and Seabrook followed the same temporal distribution in an arc like configuration which can be interpreted as a pattern of cyclicity in the way the assemblages' composition and abundance were changing over the entire course of the study (Fig.9). I generated a second MDS plot using four seasons (summer, autumn, winter, and spring) as factors to attempt to better explain the cyclical pattern. From this, it appears that the samples collected at the three geographically separate sites respond in a similar pattern to the change in seasons. Samples collected at each location during winter are more closely related to each other than samples collected at the same three locations during summer (Fig. 10).

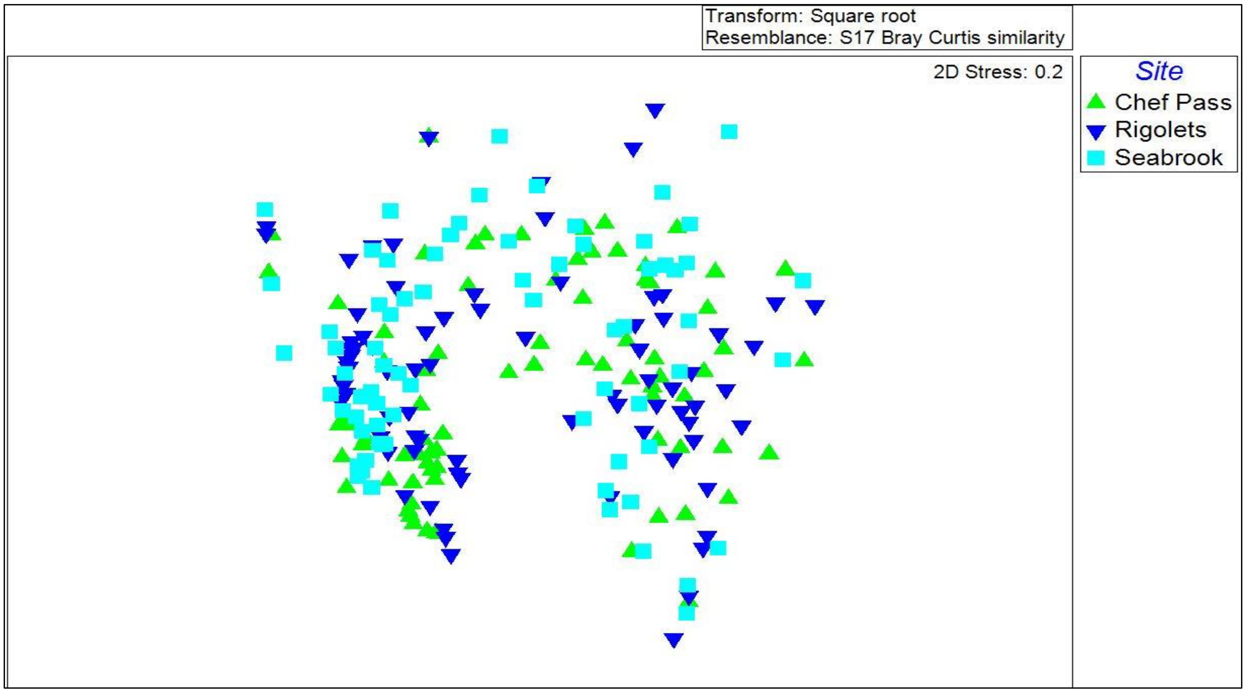


Figure 9. Multidimensional Scaling Plot (MDS) of zooplankton communities collected at Rigolets Pass, Chef Pass and Seabrook. The sampling effort was conducted from September 2009 until May 2013. The green triangles represent the samples collected at Chef Pass, the blue triangles represent the samples at Rigolets Pass and the blue squares represent the samples collected at Seabrook. From this, it appears that there are no large differences between the sites. There is an apparent variability between the samples.

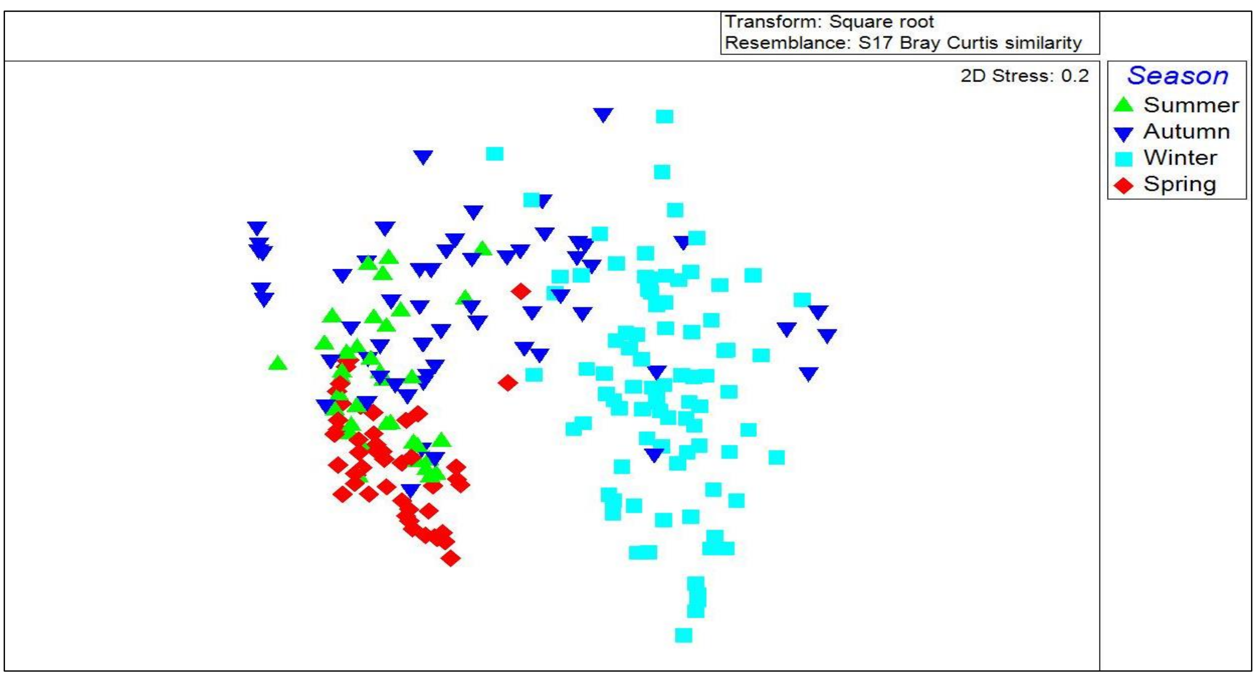


Figure 10. Multidimensional Scaling Plot (MDS) of zooplankton communities collected at Rigolets Pass, Chef Pass and Seabrook. The sampling effort was conducted from September 2009 until May 2013. The green triangles represent the summer samples, the dark blue triangles represent the autumn samples, and the light blue squares represent the winter samples and the red diamonds the spring samples. From this, it appears that the abundance and composition of the assemblages follow a seasonal pattern.

ANOSIM

The crossed two-way analysis of similarity revealed significant dissimilarities among the three sites and months sampled over the entire course of the study. More specifically there were significant differences among the aquatic invertebrates communities among the three sites groups averaged across months (ANOSIM, R= 0.162, p = 0.001; Table 4). Chef Menteur Pass and Seabrook were the most dissimilar sites (ANOSIM, R = 0.235, p = 0.001; Table 4*)* and the Rigolets and Chef Menteur Pass were more similar (ANOSIM, R= 0.118, p = 0.003; Table 4) than the Rigolets and Seabrook (ANOSIM, R= 0.129, p = 0.001; Table 4). Similarly, the two-way crossed analysis among the months groups averaged across sites yielded some significant results (ANOSIM, R= 0.523, p = 0.001; table 5). Although most paired months were significantly different, seven paired months did not have significant dissimilarities. They were as follow: October and July (ANOSIM, R= 0.134. p = 0.16; table 5), November and July (ANOSIM, R= 0.13, p = 0.14; table 5), November and August (ANOSIM, R = 0.183, p = 0.1; table 5), April and May (ANOSIM, R = 0.055, p = 0.25; table 5), April and June (ANOSIM, R = 0.109, p = 0.16; table 5), April and August (ANOSIM, R= 0.219, p = 0.06) May and June (ANOSIM, R= 0.088, p = 0.25; table 5).

Table 4. Pairwise results generated from a crossed two-way ANOSIM testing for significant dissimilarities between sites crossed with months. Asterisks indicate significant differences.

ANSOSIM Results (Sites across months)		
Groups observed	Global R	p-value
Chef Menteur Pass, Rigolets Pass	0.118	0.003*
Chef Menteur Pass, Seabrook	0.235	0.001*
Rigolets Pass, Seabrook	0.129	0.001*

Table 5. Pairwise results generated from a crossed two-way ANOSIM testing for significant dissimilarities between months crossed with sites. Asterisks indicate significant differences.

ANOSIM Results (Months across Sites)		
Group Observed	Global R	p-value
Sept, Oct	0.499	0.001*
Sept, Nov	0.664	0.001*
Sept, Dec	0.736	0.001*
Sept, Jan	0.867	0.001*
Sept, Feb	0.864	0.001*
Sept, Mar	0.992	0.001*
Sept, Apr	0.421	0.001*
Sept, May	0.467	0.001*
Sept, June	0.317	0.003*
Sept, July	0.625	0.001*
Sept, Aug	0.361	0.009*
Oct, Nov	0.285	0.002*
Oct, Dec	0.587	0.001*
Oct, Jan	0.73	0.001*
Oct, Feb	0.619	0.001*
Oct, Mar	0.867	0.001*
Oct, Apr	0.62	0.001*
Oct, May	0.658	0.001*
Oct, June	0.677	0.001*
Oct, July	**0.134**	**0.16**
Oct, Aug	0.663	0.005*
Nov, Dec	0.309	0.001*
Nov, Jan	0.499	0.001*
Nov, Feb	0.44	0.001*
Nov, Mar	0.6	0.001*
Nov, Apr	0.7	0.001*
Nov, May	0.496	0.001*
Nov, June	0.392	0.003*
Nov, July	**0.13**	**0.145**
Nov, Aug	**0.183**	**0.1**
Dec, Jan	0.133	0.016*
Dec, Feb	0.182	0.002*
Dec, Mar	0.394	0.001*
Dec, Apr	0.654	0.001*
Dec, May	0.565	0.001*
Dec, June	0.52	0.001*
Dec, July	0.461	0.001*
Dec, Aug	0.625	0.001*
Jan, Feb	0.165	0.001*
Jan, Mar	0.392	0.001*

Table 5 continued

Group observed	Global R	p-value
Jan, Apr	0.805	0.001*
Jan, May	0.756	0.001*
Jan, June	0.737	0.001*
Jan, July	0.716	0.001*
Jan, Aug	0.556	0.004*
Feb, Mar	0.463	0.001*
Feb, Apr	0.798	0.001*
Feb, May	0.835	0.001*
Feb, June	0.804	0.001*
Feb, July	0.64	0.001*
Feb, Aug	0.543	0.001*
Mar, Apr	0.932	0.001*
Mar, May	0.997	0.001*
Mar, June	0.968	0.001*
Mar, July	0.968	0.001*
Mar, Aug	1	0.01*
Apr, May	**0.055**	**0.254**
Apr, June	**0.109**	**0.169**
Apr, July	0.681	0.001*
Apr, Aug	**0.219**	**0.068**
May, June	**0.088**	**0.259**
May, July	0.588	0.001*
May, Aug	0.462	0.03*
June, July	0.704	0.004*
June, Aug	1	0.01*
July, Aug	0.778	0.01*

SIMPER Analysis

Similarity percentage analysis comparing sites group across all month groups revealed that Chef Menteur Pass had an average similarity among species of 45.37%, Rigolets Pass had an average similarity of 42.31%, and Seabrook had an average similarity of 40.64%. The species contributing the most to Chef Menteur Pass assemblage in decreasing order were *R. harrisii,* Gammarid amphipods (*Gammarus spp.),* Matagorda macoma (*Macoma mitchelli*), fish lice (*Argulus spp.),* larval fishes, mysid shrimp (*Americamysis almyra),* isopod (*Edotia montosa),* and penaeid shrimp (Table 6). The species contributing the most to similarity at the Rigolets Pass were *R. harrisii,* larval fishes, *Argulus spp., Gammarus spp., Macoma mitchelli,* copepod, penaeid shrimp, *E. montosa* and *A. almyra* (Table 7). Finally the species contributing the most to similarity at Seabrook were *R. harrisii, Argulus sp.*, *Gammarus spp.*, copepod, larval fishes and water flea (*Daphnia spp.;* Table 8).

Table 6. Similarity percentage (SIMPER) showing the species that contribute up to 90% to Chef Menteur Pass assemblage.

SIMPER Analysis Results Chef Menteur Pass (Average similarity = 45.37%)		
Species	Average Density (m^3)	Contribution %
Rhithropanopeus harrisii	1.0	41.16
Gammarus spp.	0.09	11.63
Macoma Mitchelli	0.07	11.36
Argulus spp.	0.1	7.34
Larval fishes	0.09	7.16
Americamysis almyra	0.03	5.34
Edotia montosa	0.06	3.31
Penaeid shrimp	0.08	3.13

Table 7. Similarity percentage (SIMPER) showing the species that contribute up to 90% to Rigolets assemblage.

SIMPER Analysis Results Rigolets Pass (Average Similarity = 42.31%)		
Species	Average density (m^3)	Contribution %
Rhithropanopeus harrisii	0.61	39.54
Larval fishes	0.20	10.60
Argulus spp.	0.08	10.59
Gammarus spp.	0.09	8.95
Macoma Mitchelli	0.06	8.56
Copepod	0.05	4.80
Penaeid shrimp	0.07	3.73
Edotia montosa	0.07	3.21
Americamysis almyra	0.04	2.41

Table 8. Similarity percentage (SIMPER) showing the species that contribute up to 90% of Seabrook assemblage.

SIMPER Analysis Results Seabrook (Average Similarity = 40.64%)		
Species	Average Density (m^3)	Contribution %
Rhithropanopeus harrisii	0.72	53.66
Argulus spp.	0.14	11.58
Gammarus spp.	0.03	8.63
Copepod	0.02	6.32
Larval fishes	0.04	5.33
Daphnia spp.	0.05	4.63

SIMPER analysis between each pairwise site combination and each pairwise month's combination were created because the two-way crossed ANOSIM results were significant (Table 4, 5). Similarity percentages results show an average dissimilarity of 60.85% between Chef Menteur Pass and the Rigolets. The five species contributing the most to dissimilarities between the two sites, in decreasing order, were *R. harrisii, Gammarus spp.*, larval fishes, *Argulus spp.*, and *M. mitchelli* (Table 9). The average dissimilarity for Chef Menteur Pass and Seabrook was 66.20%. The five species contributing the most to dissimilarities between the two sites, in decreasing order, were *R. harrisii, M. mitchelli, Gammarus spp., Argulus spp.,* and larval fishes (Table 10). Finally, the average dissimilarity between the Rigolets and Seabrook was 63.89%. The five species contributing the most to dissimilarities between the two sites, in decreasing order, were R. *harrisii, Gammarus spp.*, larval fishes, *M. mitchelli,* and copepod (Table 11). The species that contributed the most to overall dissimilarity between the three sites was *R. harrisii* with 21.74% contribution to dissimilarity between Chef Menteur Pass and Rigolets Pass, 21.36% between Chef Menteur Pass and Seabrook and 16.20% between the Rigolets and Seabrook (Table 9, 10, 11). SIMPER analysis between each pairwise month's combinations revealed that changes in abundance of *R. harrisii*, *Argulus spp.*, *M. mitchelli*, *Gammarus spp*., larval fishes were the primary species causing dissimilarities between each combination of compared months (Appendix I).

Table 9. Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between Chef Menteur Pass and the Rigolets. The contribution % indicates how much a species contributed to the overall dissimilarities between the two sites.

SIMPER Analysis Results Chef Menteur Pass & Rigolets Pass (Average Dissimilarity = 60.85%)				
Species	Chef Menteur Pass Average Density (m^3)	Rigolets Pass Average Density (m^3)	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	1.00	0.61	13.23	21.64
Gammarus spp.	0.09	0.09	6.93	11.38
Larval fishes	0.09	0.20	5.67	9.32
Argulus spp.	0.10	0.08	5.58	9.17
Macoma mitchelli	0.07	0.06	5.27	8.66
Americamysis almyra	0.03	0.04	4.44	7.29
Copepod	0.04	0.05	4.21	6.92
Cerapus tubularis	0.05	0.07	3.52	5.79
Edotia montosa	0.06	0.07	2.76	4.53
Penaeid Shrimp	0.08	0.07	1.70	2.79
Unknown	0.02	0.01	1.63	2.67

Table 10. Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between Chef Menteur Pass and Seabrook. The contribution % indicates how much a species contributed to the overall dissimilarities between the two sites.

SIMPER Analysis Results Chef Menteur Pass & Seabrook (Average Dissimilarity = 66.20%)				
Species	Chef Menteur Pass Average Density (m^3)	Seabrook Average Density (m^3)	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	1.00	0.72	14.14	21.36
Macoma mitchelli	0.07	0.01	7.79	11.76
Gammarus spp.	0.09	0.03	7.51	11.34
Argulus spp.	0.10	0.14	6.92	10.45
Larval fishes	0.09	0.04	4.77	7.20
Americamysis almyra	0.03	0.01	4.07	6.15
Copepod	0.04	0.02	3.94	5.95
Cerapus tubularis	0.05	0.01	3.44	5.19
Daphnia spp.	0.01	0.05	2.91	4.40
Edotia montosa	0.06	0.05	2.71	4.09
Unknown	0.02	0.01	1.98	2.99

Table 11. Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between the Rigolets Pass and Seabrook. The contribution % indicates how much a species contributed to the overall dissimilarities between the two sites.

SIMPER Analysis Results Rigolets Pass & Seabrook (Average Dissimilarity = 63.89%)				
Species	Rigolets Pass Average Density (m^3)	Seabrook Average Density (m^3)	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.61	0.72	10.35	16.20
Gammarus spp.	0.09	0.03	8.09	12.67
Larval Fishes	0.20	0.04	7.00	10.95
Argulus spp.	0.08	0.14	6.44	10.08
Macoma mitchelli	0.06	0.01	6.30	9.86
Copepod	0.05	0.02	5.93	9.28
Americamysis almyra	0.04	0.01	4.23	6.63
Cerapus tubularis	0.07	0.01	4.06	6.35
Daphnia spp.	0.02	0.05	2.47	3.86
Edotia montosa	0.07	0.05	2.35	3.68
Unknown	0.01	0.01	2.11	3.30

BIO-ENV

BIO-ENV analysis was performed to determine the relationship between biotic (aquatic invertebrate assemblages) and abiotic data (meteorological data, water quality). A total of seven variables (tide, wind direction, wind speed, dissolved oxygen, salinity, water temperature, and secchi disk depth) were used in BIO-ENV. While the results indicated that water temperature contributed the most to changes in the composition of aquatic invertebrates' communities at Seabrook (BIO-ENV, Spearman Correlation Value = 0.363; Table 12) and at Chef Menteur Pass (BIO-ENV, Spearman Correlation Value = 0.380, Table 13), a combination of wind speed, dissolved oxygen and water temperature contributed strongly to the aquatic community compositions 'changes at the Rigolets (BIO-ENV, Spearman Correlation Value = 0.475; Table 14).

Table 12. BIO-ENV analysis results for Seabrook. The variables used for the analysis were tide, wind direction, wind speed, dissolved oxygen salinity, temperature and secchi readings. Temperature contributed the most to differences in the aquatic invertebrate community composition.

BIO-ENV Best Results (Seabrook)		
Number of variables	Spearman correlation	Selections
1	0.363	Water Temperature
2	0.357	Wind Speed, Water Temperature
2	0.353	Dissolved Oxygen, Water Temperature
3	0.347	Wind Speed, Dissolved Oxygen, Water Temperature
4	0.346	Wind Direction, Wind Speed, Dissolved Oxygen, Water Temperature
3	0.344	Wind Direction, Wind Speed, Water Temperature
3	0.342	Wind Direction, Dissolved Oxygen, Water Temperature
2	0.341	Wind direction, Water Temperature
5	0.334	Wind Direction, Wind Speed, Dissolved Oxygen, Water Temperature, Secchi
4	0.325	Wind Speed, Dissolved Oxygen, Water Temperature, Secchi

Table 13. BIO-ENV analysis results for Chef Menteur Pass. The variables used for the analysis were tide, wind direction, wind speed, dissolved oxygen salinity, temperature and secchi readings. Temperature contributed the most to differences in the aquatic invertebrate community composition.

BIO-ENV Best Results (Chef Menteur Pass)		
Number of variables	Spearman correlation	Selections
1	0.380	Water Temperature
2	0.345	Dissolved Oxygen, Water Temperature
3	0.337	Dissolved Oxygen, Salinity, Water Temperature
2	0.321	Salinity, Water Temperature
2	0.310	Water Temperature, Secchi
3	0.308	Wind Speed, Salinity, Water Temperature
3	0.302	Dissolved Oxygen, Water Temperature, Secchi
4	0.302	Wind Speed, Dissolved Oxygen, Salinity, Water Temperature
4	0.299	Dissolved Oxygen, Salinity, Water Temperature, Secchi
4	0.293	Tide, Dissolved Oxygen, Salinity, Water Temperature, Secchi

Table 14. BIO-ENV analysis results for the Rigolets. The variables used for the analysis were tide, wind direction, wind speed, dissolved oxygen salinity, temperature and secchi readings. A combination of wind speed, dissolved oxygen and water temperature contributed the most to differences in the aquatic invertebrate community composition.

BIO-ENV Best Results (Rigolets Pass)		
Number of variables	Spearman correlation	Selections
3	0.475	Wind Speed, Dissolved Oxygen, Water Temperature
2	0.463	Wind Speed, Water Temperature
4	0.451	Wind Speed, Dissolved Oxygen, Salinity, Water Temperature
1	0.431	Water Temperature
4	0.408	Tide, Wind Speed, Dissolved Oxygen, Water Temperature
3	0.407	Wind Speed, Salinity, Water Temperature
2	0.404	Dissolved Oxygen, Water Temperature
2	0.404	Wind Speed, Water Temperature
4	0.398	Wind Direction, Wind Speed, Dissolved Oxygen, Water Temperature
5	0.393	Tide, Wind Speed, Dissolved Oxygen, Salinity Water Temperature

Discussion

Compositional differences in aquatic invertebrate communities among the three sites (site location)

Rhithropanopeus harrisii was by far the most abundant species collected at each of the sites with an overall contribution of 89.22% to the total collection. Although, *R.harrisii* accounts for the greatest abundances of all species collected during the study, *R.harrisii* generally displayed distinct peak abundances in April, May and June, followed by a second peak in abundance in August and September. These periods of high abundance were usually followed by *R. harrisii* being present in samples in very low numbers to being totally absent. Low abundances periods occurred from October throughout March at the three sites. With the exception of one *Lucifer faxoni* collected at the Rigolets Pass, species richness was comparable at the three sites (Fig.8). There were significant differences among species abundances among the three sites (Table 1, 2, 3).

The dissimilarities among the three sites species community abundance and composition could be explained by their geographical location and physical environments. The Seabrook site is located on an artificial tidal inlet connecting the Mississippi River to the industrial canal and to the Inner Harbor Navigational Canal. This site is located in the south eastern area of Lake Pontchartrain and has been subjected to increased urban and suburban development over the years. The loss of vegetated areas due to the construction and expansion of concrete seawalls and riprap along the inner harbor navigational canal and the south shore of the Lake has transformed potential settlement areas into inadequate deeper and high energy environment areas, unsuitable to many species (O'Connell, *et al.*, 2007). In contrast, Chef Menteur Pass and the Rigolets Pass (located northeast of the Seabrook site) are surrounded for the most part by intermediate marsh. It should also be noted that the Rigolets is bordered to its north side by fresh water marsh (EPA map, Fig. 3).

Intermediate marsh offers a diversity of both fresh water and brackish water plant species and is dominated by saltmeadow cordgrass (*Spartina patens*). This type of marsh is classified as oligohaline due to salinity levels ranging from 3 to 10. Freshwater marshes are known to have the greatest plant diversity and highest soil organic matter content of any type of marsh (Leister, *et al.*, 2005). The salinity in that type of marsh ranges from 0.5 to 1. The proximity of intermediate and freshwater marsh near Chef Menteur Pass and the Rigolets noticeably increased the amount of organic detritus collected during sampling effort at these two sites than at Seabrook (personal observation). The contiguity of marsh by the sampled areas is important because it likely provides numerous aquatic invertebrates species with more diverse and complex types of habitats. Habitat complexity is one of the most important factors structuring biotic assemblages (Kovalenko, 2012). These areas of high productivity, also known as Critical Transition Zones (CTZs), are important because they provide essential ecosystem services such as shoreline protection, habitat, and food for migratory and resident animals. They are, however, subjected to extreme fluctuations in water salinity, temperature, and dissolved oxygen. These areas are among the most productive areas in the world. However this high productivity is accompanied by low species richness (Levin, et al., 2001). Benthic invertebrates such as copepods, mollusks, and peracarid crustaceans are common in these areas due to the large amount of organic material originating from the detritus and algae on which they forage. This in return allows for high secondary production rates. Sediment dwelling organisms in conjunction with structurally complex habitat provide a critical nursery habitat for numerous commercially important species like *C. sapidus, F. aztecus,* and *L. setiferus* which feed on those potential prey items but also use their surroundings as refugia from predators.

Another important aspect of site selection by various species is their response to chemical cues which varies based on their surrounding environments. Estuarine humic acids are decomposition products of structural elements of plant material such as smooth cordgrass (*Spartina alterniflora*) which is abundant in many estuaries. This particular chemical decreases from the head to the mouth of this estuary due to precipitation and dilution due to the increase in salinity. Forward, *et al*., (1997) demonstrated that dissolved humic acids along with other chemical cues emitted by different types of aquatic vegetation could accelerate metamorphosis in recruiting *C. sapidus* megalopae and trigger subsequent settlement in suitable habitats (Fig. 1). These types of chemical cues would be more likely to be important at the Rigolets and Chef Menteur Pass sites due to their location near marsh areas than Seabrook which essentially lacks marsh vegetation and is located in a heavily urbanized area.

Compositional differences in aquatic invertebrate communities throughout the year and at the three sites: seasonality, and, variation in abiotic factors

A total of seven variables (tide, wind direction, wind speed, dissolved oxygen, salinity, water temperature and turbidity) were used to assess possible influences on any changes in the aquatic invertebrates' communities. Water temperature was found to be the main variable responsible for changes in species composition at Chef Menteur Pass (BIO-ENV, Spearman Correlation Value = 0.380, Table 13) and Seabrook (BIO-ENV, Spearman Correlation Value = 0.363, Table 12). A combination of wind speed, dissolved oxygen and water temperature was found to be the likely strongest influences on changes in the community composition at the Rigolets (Spearman Correlation Value = 0.475, Table 14).

Water Temperature

Water temperature was found to be the most likely abiotic factor affecting the composition of the aquatic invertebrate communities at both the Seabrook and Chef Menteur Pass (Table 12, 13). Water temperature graphs for the three sites between September 2009 and May 2013 (with the exception of a period between May 2011 and August 2012) exhibit a clear seasonal cycle characterized by summer warming and winter cooling. The water temperature distribution over the study period was similar among the three sites (Appendix II-A).

Changes in water temperature are often responsible for driving behavioral, physiological and reproductional patterns in animals (Chen and Folt, 2002). The performance of many organisms depends on the variation in temperature associated with seasonal changes. Primary productivity is triggered by an increase in photoperiod and solar radiation, allowing for an upsurge in photosynthesis and growth rate. Subsequently, during early spring, large blooms of diatoms are produced and grazed upon by herbivorous copepods. A significant fraction of the diatoms sinks to the bottom where it is consummed by benthic organisms (Cloern, *et al.*, 2014; Johnson and Allen, 2005).

Water temperature and species at the Rigolets Pass, Chef Menteur Pass, and Seabrook

In general, as water temperature increased during early spring so did species abundance. The eight species contributing the most to the community composition at the Rigolets, namely *R. harrisii,* Larval fishes*., Argulus spp., Gammarus spp., M.mitchelli,* copepod, penaeid shrimp, *E.*

montosa, and *A. almyra*, increased in abundance during water warming events. Although, all the species abundances did occur during a water warming event, the season at which it took place differed. At the Rigolets Pass, *M. mitchelli* specimens were present in the samples starting in December 2009, peaked in January 2010 with 92 specimens collected followed by a second larger peak in April 2010 with 102 specimens collected. The largest recorded peak occurred in January 2011 with 166 specimens collected. Finally, the last recorded peak was in February 2013 but with only 18 specimens (Appendix II-B) A similar pattern of temporal distribution occurred at Chef Menteur Pass. *M. mitchelli* specimens were collected in February and April 2010 but in lower numbers (31 and 24 respectively) than at the Rigolets Pass for the same time period. A less important peak was recorded in January 2011 with only 17 specimens collected. Finally, the last two major peak occurred in December 2012 (282 specimens collected) and in January 2013 (197 specimens collected, Appendix II-C). *Macoma balthica,* a closely related species to *Macoma mitchelli,* in the Wadden Sea, are known to have two migration phases during its early life history. Spawning occurs in March and April. In May the postlarvae migrates to the nursery grounds and settle on high silty tidal flats. This is is considered to be the spring migration. After the first growth season, the juveniles undergo a winter migration, between December and March, from the nurseries to the low intertidal flats (Hiddink & Wolff, 2002). The pattern of increase in the number of *M. mitchelli* at the Rigolets Pass potentially fits the aforementioned winter migration in the Wadden sea described by Hiddink *et al.*(2002).

Various peaks in abundance of *Gammarus spp.*occured during the course of this study but the most noticeable one occurred in January 2010, at the Rigolets Pass, with 293 specimens collected followed by two lesser peaks in abundance in April 2010 and August 2010. April 2011 produced the second largest peak in abundance with 153 specimens collected and finally the last peak was recorded in February 2013 with 84 (Appendix II-D). This species is known to have many feeding strategies. The scrapers feed on organic biofilm also known as aufwuchs (MacNeil *et al*., 1997). The shredders collect allochthonous detritus. The filterers feed on organic suspended matter and the herbivore shredders and piercers feed on macrophytes. Species, such as *Gammarus pulex,* are known to feed on allochthonous leaf litter. Interestingly, the peak in abundance observed in early winter could be associated with the intial production of autumnal leaf litter. The specimens collected could be the remnants of a *Gammarus spp.* congregation (MacNeil, *et al.*, 1996). Another explanation for the presence of *Gammarus spp.* in the water column at this time of the year is due to the low water levels. Areas that were once suitable for *Gammarus spp.* to thrive would be suddenly out of the water thus leading to an exodus into deeper waters. Peaks in abundance in April at Chef Menteur Pass and the Rigolets Pass in 2011 could be associated with an increase in primary productivity. The increase in plant mass in spring could provide asubsequent amount of food which in return would translate in greater amount of *Gammarus spp.*. Although *Gammarus spp.* abundance at Seabrook was low compared to the other two sites, with an overall contribution of 8.04% of the total specimens collected, the temporal distribution was somewhat similar.

Copepods are the most abundant animals in the mesozooplankton (Johnson & Allen, 2005). During the study sampling effort, copepods had their largest peaks of abundance at the Rigolets Pass in December 2009 (56 specimens), February 2010 (57 specimens), February 2011 (38 specimens) and April 2011 (52 specimens, Appendix II-H). At Seabrook, peaks in abundance were recorded in December 2009 (7 specimens), March 2010 (15 specimens), and December 2010 (22 specimens, Appendix II-G). The increase in abundance of copepods during the winter months could be related to a decline in higher trophic organisms. Comb jelly

(*Mnemiopsis spp.*) is the most abundant nearshore ctenophore with densities nearing 100 m^{-3} in summer. It is usually found in higher salinity water but it is common, during the fall, in salinities as low as 5 (Johnson and Allen, 2005). These voracious ctenophores were present in large numbers during fall at the three locations with larger numbers at the Rigolets and Chef Menteur Pass (personal observation). *Mnemiopsis spp* have the potential to exert tremendous pressure on all life stages of copepods, crab zoea, gatropods veligers, and barnacle nauplii. Average rates of clearance of zooplankton *Mnemiopsis spp.* in Long Island were estimated to be 20% per day and ranged up to 90% per day. In Chesapeake Bay, during high abundance the estimated rate of clearance was 23 to 32% per day and increased by increasing ctenophores abundances (McNamara and Lonsdale, 2010). The presence of *Mnemiopsis spp.* is thought to be linked to a combination of temperature, salinity and food availibility at various times of the year and is dependent on the geographical location (Shiganova, *et al*., 2001). This could explain a drop in the number of ctenophores observed in the field during the colder months and lower salinities associated with this period of the year. During the entire course of the study, 500 μ mesh size bongo nets were used. The reason why this mesh size was used is that finer meshes often become clogged with phytoplankton when sampling coastal waters (Turner J. T., 2004). The proper size mesh to collect copepods was shown in recent studies to be 100 μ or less. Thus, the abundance of small copepod was probably underestimated due to the size of the mesh used.

The largest largest peak of *Americamysis almyra* ocurred at Chef Menteur Pass in December 2009 (31 specimens) and December 2012 (16 specimens, AppendixII-I). This mysid species, plays a key role in structuring estuarine communities. Mysids are intermediate in size as prey items, between mesozooplankton and endo or epibenthic size, and are consumed by small crutaceans and fishes (Vilas, *et al.*, 2007). Their presence during the colder months is probably related to a decrease in the numbers of predator such as ctenophores, fishes, and crustaceans.

At Seabrook, *Daphnia spp.* exhibited a clear peak in abundance in December 2009 (103 specimens) and in April 2010 (33 specimens, Appendix II-J). *Daphnia spp.* are among the most common freshwater zooplankton. Similarly, the occurrence of this species of cladoceran happens to be during the colder months. The low numbers or predators could also explain the increase in their overall numbers. In Lake Oglethorpe, the low density of *Daphnia parvula* was showned to be strongly related to the presence of the predator *Chaoborus sp.* (Orcutt and Porter, 1983). This invertebrate predator was abundant through the summer and showed an inverse relationship in abundance with *Daphnia* species. Furthermore, planktivorous fishes were more active during the warmer month thus negatively impacting on resident daphnid populations (Orcutt and Porter, 1984). The same pattern of predation, on *Daphnia spp.*,could be applied in Lake Pontchartrain where an increase in crustaceans and fishes is common during the warmer months.

A similar pattern in temporal distribution was displayed by *Rhithropanopeus harrisii* at the three sites (Fig. Appendix II-K,L,M). *R. harrisii* was typically present in the samples from April until November with varying degrees of abundance depending on the location. The first peak in abundance every year and at the three locations occurred in April. Generally, April was the month which displayed some of the greatest abundances. A second but lesser peak in abundance generally occurred in August and September. The observed breeding season for *R. harrisii* in North Carolina is from May to September in the Newport Estuary (Costlow John D., 1966). Other studies, demonstrated that the breeding season in the Neuse River and Newport river could extend as early as mid-April to mid-October (Goy, *et al.*, 1985) which is similar to the what I observed during the course of my study. Although, the optimum water temperature range for development of *R. Harrisii* is 20 to 25 °C, the development of stage I zoea to first crab stage can occur in water temperature as low as 15 °C and as high as 35 °C (Forward, 2009). This species is a highly successful invader which has colonized various environments spanning from two oceans, 10 seas and many inland reservoirs (Roche and Torchin, 2007). It was reported that population of *R. harrisii* in the Vistula River, Poland, could survive water temperature nearing 1°C and even survive freezing conditions for a short period of time (Turoboyski, 1973). At the Northern edge of their range, in the Miramichi Estuary, Canada, populations are exposed to near freezing salt water temperature for up to six months. The water temperature recorded in the Miramichi Estuary between May and September in 1992 ranged from 4 °C in May to to a maximum of 23 °C in August. Zoea and megalopa of *R. harrisii* first appeared in July and were nearly present in all water in August throughout September (Locke and Courtenay, 1995). In the Northern Baltic sea, *R. harrisii* was first observed of the coast of southwest Finland in 2009. Water temperature in the Baltic Sea ranges from 4°C to 20 °C. In the archipelago of southwestern Finland, ovigorous females were collected from July to October when the water temperature typically reaches 14°C and above (Fowler, *et al.*, 2013). Both reproducing adults and young of the year were oberved simultaneously, off the coast of southwest Finland which further indicated that *R. harrisii* was able to survive winter conditions in the Northern Baltic Sea. During the colder months, denser and warmer water sinks to the bottom of the Baltic Sea allowing for the water temperature to remain aound 4°C (Fowler, *et al.*, 2013). This stable water temperature, at the bottom of the sea, acts as a thermal refugia for *R.harrisii* during the winter months when adverse weather conditions are less than favorable for its survival. Although various studies have shown that *R. harrisii* is able to survive and reproduce in a wide range environmental conditions, studies have also shown, in order to successfully reproduce water temperature should be above 15 ºC.

Larval fishes were present at the three sites with different abundances (Appendix II-N,O,P). The Rigolets Pass and Chef Menteur Pass had the greatest larval fishes abundance. These two sites offer both a more direct routes in and out Lake Pontchartrain and more habitats in term of quality and diversity than Seabrook does. Generally, the largest peaks in larval fishes abundance at the three location occurred from February until May. Spring warming events, in terms of water temperature, corresponded with the first large pulses . Although, the larval fishes were not idenitified to their lowest taxonomic groups, a previous study determined that the most dominant species contributing to the larval fish assemblages at the three sites were *Anchoa mitchilli* (Bay Anchovy), *Brevoortia patronus* (Gulf Menhaden) and *Menidia beryllina* (Inland Siverside) (Cope, 2013).

Specimens of *Argulus spp.* were present at the three sampled locations (Appendix II-Q,R,S). Early peaks in abundance typically occurred during early water warming events associated with the advent of spring and continued throughout the year until the water temperature dropped which is typical of the fall cooling pattern. *Argulus spp.* development time for all phases is heavily dependent on water temperature with a faster growth rate at higher water temperature (Walker, 2008). It takes eight days for the eggs of *Argulus foliaceus* to hatch in water temperatures of 26 ºC and a few months at temperatures below 10 ºC. Two *Argulus* species occurring in Finland have different behavioral responses to low water temperature. *Argulus coregoni* spends winter only in the form of resting eggs whereas *Argulus foliaceus* has two different overwintering strategies which are to either remain attached to its host while slowing down its overall activities or by overwintering in the form of resting eggs or sometimes both strategies are used (Hakalahti, *et al.*, 2004). As the eggs stay dormant for the winter, the rise in water temperature causes some eggs to hatch in early spring and the metanaupli will make up the first pulse of the population. Hatching will continue to occur later into spring to allow for an extended recruitment (Taylor, *et al.*, 2005). Two to three reproductive seasons and continuous egg laying periods from May to October have been observed in *A. foliaceus* and *A .japonicus* (Taylor, *et al.*, 2005). This reproductive pattern is somewhat similar to oberved local population of *Argulus spp.,* althought the breeding and egg laying season appears to start earlier and end later in a year due to the subtropical climate conditions here in Louisiana versus the temperate climate experienced where most of these other studies were conducted.

Penaeid shrimp were present in the samples twice a year during the course of the study (Appendix II-T,U). Two pulses generally occurred at the sites, the first one in April and the second one around September. At the time of field collection, water temperature was always above 20 ^{o}C when the two species were collected. Although, *F. aztecus* and *L. setiferus*, spawn and undergo larval development at sea, both species recruit back into the estuary at different time during the year. For *F. aztecus* recruitments event occur between March and April whereas *L. setiferus* recruits during late summer. Both species have different water temperature tolerances where *F. aztecus* is exposed to temperature not only varying from 15 to 25^{o}C but also to temperature reaching 12 ^{o}C due to the influence of atmospheric cold fronts still occurring at this time of the year. This species has developed a strategy to cope with sudden drop in water temperature which consists of burrowing itself into the substrate when temperatures fall in the range of 12 to 17^{o}C. They then emerged from their burrows when temperatures become more favorable at around 18 to 21^{o}C (Aldrich, *et al.*, 1968). For *L. setiferus*, recruitment is late during the summer, when temperatures are consistently in the 25 to 32ºC range (Aldrich, *et al.*, 1968). Interestingly, of the two aforementioned species, only *F. aztecus* has developed such an ecological mechanism enabling itself to survive harsh environmental conditions. Both observed pulses are consistent with published literature describing observed temporal distribution of *L. setiferus* and *F. aztecus* in the northern Gulf of Mexico (Cook and Lindner, 1971). This pattern of temporal partitioning results in an interspecific positive relationship between *F. aztecus* and *F. setiferus*, where competition for resources, is quasi inexistent.

Peak in abundance for *Edotea montosa* occurred during the period of high primary productivity at the Rigolets Pass and Chef Menteur Pass (Appendix II-V,X). The greater number of this species of epiphytic grazer at the Rigolets Pass could be explain by the proximity of intermediate marshes, an essential source of food, and shelter. In addition, the Rigolets Pass is directly influenced by the Pearl River. Therefore, the sudden increase of *E. montosa* in the samples could be related to high river stages or storm events. Normaly low energy habitats suddenly become inundated and exposed to higher flow velocities, thus entraining both vegetation and detritus and various species of grazers including *E. montosa* into the water column.

Dissolved oxygen

The recorded dissolved oxygen levels were somewhat similar at the three sites with higher values recorded during fall and winter and lower values during recorded during spring and summer. Out of the three sites, Seabrook dissolved oxygen levels fluctuated the most (Appendix III-A).

Low dissolved oxygen levels are common in numerous aquatic system that have high nutrient loading, seasonal stratification, and long water residence time and can lead to hypoxia. The estuaries of the Northern Gulf of Mexico are categorized as shallow water systems with tidal fluctuation, varying between 0.3 to 0.6 meters and where water temperatures are relatively constant during the summer. Low dissolved oxygen levels are common during the early morning and are potentially caused by the combination of high biological oxygen demand due to organism respiration combined with poor mixing of the water column due to a decrease in wind intensity at night (Engle, *et al.*, 1999). High nutrient loading which can be of anthropogenic origin can also lead to the depletion of oxygen levels due to an increase in microbial oxygen demand during the decomposition of organic matter. Hypoxic events in Lake Pontchartrain are generally periodic and typically associated with high nutrient loading from tributaries or from the Mississippi River (McCorquodale, *et al.,* 2009). During the course of the study, the site at Seabrook displayed the greatest fluctuation in dissolved oxygen levels whereas the Rigolets and Chef Menteur Pass exhibited more evenly distributed dissolved oxygen levels. Seabrook is located in a highly urbanized area. One of the dominant hydrological features of urbanized area, compared to a forested area, is the decrease in imperviousness of the catchment to precipitation leading to an increase in surface runoff.

Although the Inner Harbor Navigational Canal is not classified as a stream, the term urban stream syndrome could be easily applied to it. Urban stream syndrome is characterized by various syndromes such as a flashier hydrograph; elevated concentrations of nutrients and contaminants; and reduced biotic richness with the presence or absence or more dominant species (Meyer, *et al.,* 2005; Walsh, *et al*., 2005). SIMPER analysis results revealed that

Seabrook had only six species contributing up to 90% to its community compared to 9 species for Rigolets Pass and 8 species for Chef Menteur Pass assemblages (Tables 6, 7, 8).

Interestingly, out of the three sites sampled, only the assemblages at the Rigolets Pass were significantly affected by dissolved oxygen conditions combined with wind speed and water temperature.

The number of specimens of *Argulus spp.* collected clearly increased from March 2010 untill November 2010 (Appendix III-B). During this period, the level of dissolved oxygen were some of the lowest recorded at the Rigolets Pass. It is difficult to directly attribute the increase in specimens collected to the dissolved oxygen levels. In a study conducted by Harrison *et al.* (2006) in Northern Ireland, the changes in level of dissolved oxygen were never more than 0.4 mg/L and were thought not to be significant enough to directly elicit a change in habitat use. However, a small change in oxygen level at various depth could have subltle effects on the habitat utilisation of numerous organisms in the food web thus leading to a habitat shift by the host fish of *Argulus spp.* Similarly, the variation in dissolved oxygen during my study could have lead to an escape response by the host fish of local *Argulus spp.* thus explaining the increase of specimen present in the water column.

Increase in larval fishes at the Rigolets Pass commonly occurred in April and May when dissolved oxygen levels were low (Appendix III-C). In order to reach suitable habitats, such as submersed aquatic vegetation in Lake Pontchartrain, larval fishe have to make their way up the estuary through the tidal passes. Due to the low dissolved oxygen at depth, it is possible that the presence of larval fish would correspond with an increase in prey items in the upper reaches of the water column. This increase in prey item would be the consequence of a low dissolved oxygen level resulting in a compressed habitat scenario. In a study conducted in the Patuxent River, Chesapeake Bay, the results indicated that low dissolved oxygen would result in a vertical overlap of fish larvae with their prey thus potentially leading to important changes in the community structure (Keister, *et al.*, 2000).

It is difficult to find a clear pattern in copepods peak abundance because they occurred in December 2009, February 2010, February 2011 and April 2011 and the dissolved oxygen levels were differents during the aforementioned months (Appendix III-D). Generally, copepod were more scarce during the warmer months and more common in colder month. A decrease in predation rates during the colder months resulting from a decline in comb jelly (*Nemopsis spp.*) and planktivorous fish could explain the increase in specimens collected.

With the exception of April 2010, *Macoma mitchelli* generally occurred during the colder months (Appendix III-E). A closely related species to *M. mitchelli, M. balthica*, migrates twice during the benthic part of its life, in May-June and then seven to nine month later between December and February (Hiddink and Wolff, 2002). This species was observed to primarily migrate at night and during high turbidity events. Dissolved oxygen concentrations are higher during colder months in Lake Pontchartrain. In addition, during winter, strong northerly winds associated with frontal passages, have for effect to increase wave actions in the lake thus facilitating the diffusion of oxygen into the water. This increased in wave action drastically increases the water turbidly. Consequently, *M. mitchelli* take advantage of the reduced visibility to enter the water column thus avoiding predation.

Penaeid shrimp appeared in the sample during early spring and late summer. Two peaks occurred in April 2010 and April 2011 (Appendix III-F). The levels of dissolved oxygen at the time of occurrence were typically low. Recruitment back to the estuary, for both *Litopenaeus setiferus* and *Farfantepenaeus aztecus*, corresponds with an increase in primary production often time associated with low dissolved oxygen due to increase bacterial activity. Both species are omnivorous and are known to feed on phytoplankton and zooplankton. As they reach farther into their obligate nursery habitat, postlarvae become demersal and actively feed on marsh grass and plant material detritus. Consequently, the timing of the recruitment by both species proves to be highly beneficial to their development into adult.

The presence of *Gammarus spp.* during the colder months at the Rigolets Pass but also in April demonstrates that *Gammarus spp.* (Appendix III-G) can tolerates various levels of dissolved oxygen. Similarly to other grazers, its presence in the water column could be explained by differences in water level cause by frontal passage or high river stage depending on the time of the year. Furthermore, the lower level of rates of predation during the colder months could explain the higher number of specimens collected.

Greater numbers of specimens of *Edotea montosa* were present in the samples during the warmer months during which the lowest dissolved oxygen levels were recorded (Appendix III-H). *E. montosa*, as a grazer, is strongly associated with vegetation and shows poor swimming capabilities (Bostrom and Mattilda, 1999). During the transition period between a cooler to a warmer season, increase in rainfalls are common. The Rigolets Pass is greatly influenced by the Pearl River system and receives copious amount of freshwater and detritus from decaying plant material. This input in nutrient explains the decrease in dissolved oxygen due to enhanced microbial activity. Additionally, *E. montosa specimens* were most likely “flushed out” from their preferred vegetated habitat during high river flow.

Pulses of *Rhithropanopeus harrisii* generally occurred during low dissolved oxygen events (Appendix III-I). Population of *R. harrisii* peak during low dissolved oxygen levels generally in April. Similarly to previously described response of other species to low level of dissolved oxygen, *R.harrisii* occurrence is timed with an increase of primary productivity. As an omnivorous crab species, the Harris mud crab is able to feed on various items ranging from detritus as well as animal and plant matter. Xanthid crab larvae are known to consume Brine shrimp nauplii (*Artemia spp.)* during laboratory experiments (Hood and Carey, 1962). In a natural setting, it is then possible for *R. harrisii* zoea to feed on various copepod species present in large number as a direct result of increased primary production.

Physical forcing events (e.g., tidal forcing, wind forcing) affecting the composition of the aquatic invertebrate communities.

The results from BIOENV revealed that the Rigolets' community composition was strongly influenced by wind speed (Table 14). The water levels in Lake Pontchartrain are influenced by a combination of Gulf tides and the easterly winds that drive water into the Lake (Cho, 2007). Prior to the closure of the MRGO in 2009, the Rigolets Pass had the largest exchange flow, among the three tidal inlets, with 64% (Haralampides, 2000). The Rigolets Pass is the largest of the three tidal inlets with a total length of 14.5 km and a cross sectional area of 7500 m^2 (Cho, 2007). An important factor when it comes to tidal movement in Lake Pontchartrain is the orientation of the Rigolets Pass which runs east-west. In a study conducted by Cho (2007), the numbers of days with each daily resultant wind direction were compiled from October 21, 1996 until May 21, 2001. The results showed that overall the easterly winds occurred more often than westerly winds. In winter (December-February), northerly winds prevailed, followed by a switched to south-southeast winds during March through June. Finally, West winds dominated July and August to later become northeast from September through November.

Wind patterns during the course of my study were very similar to the ones described by Cho (2007). I chose to focus on particular sets of months every year from 2009 until 2013. Generally, pulses of holoplankton and meroplankton occurred in April and in September. Consequently, I chose the wind data (wind speed and direction) from the months leading to pulsing events and the months during which pulsing events occurred. I then generated wind roses to better visualize the potential relationship between recruitment events of certain species at the Rigolets Pass and the wind direction and speed (Appendix IV-A).

Tides strongly influenced by wind play an important role in larval recruitment in many estuarine systems around the world. Wenner *et al.* (1998) studied the potential recruitment mechanisms of *L. setiferus* near North Edisto Inlet, South Carolina. The results of the study indicated that downwelling-favorable winds having an onshore component played a role in the transport process. High concentrations of larvae were pushed towards the coast by an onshore flow at the surface. Consequently, the larvae were forced towards shallow habitats and closer to the tidal inlets thus facilitating their transport up estuary. Likewise, increased number of penaeid shrimp collected at the Rigolets Pass occurred when winds had an east component. During April 2010, the first recorded pulse of penaeid shrimp at the Rigolets Pass happened in conjunction with winds originating from the southeastern quadrant. The following September, another pulse occurred with strong winds with an easterly component. Finally, the largest pulse occurred in April 2011 with strong winds associated from the south eastern quadrant (Appendix IV-B). This pattern is similar to what has been observed in other studies (Wenner *et al.,* 1998; Larson *et al.,* 1989) and further underline the importance of wind forcing events on the life cycle of commercially and environmentally important penaeid shrimp species. Some estuarine-dependent fish species are also known to take advantage of wind driven currents. Although, fish larvae were not identified during the course of the study, two noticeable recruitment events happened at the Rigolets. The first one occurred in April 2010 and the second one in April 2011. Both happened during a strong wind with a southeastern component (Appendix IV-C). Cope (2013) found that the three most numerous larval fishes species at the Rigolets Pass were Bay anchovy (*Anchoa mitchilli*), Gulf menhaden (*Brevoortia patronus),* and Inland Silverside (*Menidia beryllina*). Gulf Menhaden supports an important commercial fishery in the Gulf of Mexico. Larvae begin migration from offshore waters as early as October and continue throughout May. Peaks in recruitment occur in Louisiana passes occur during November–December and February-April (Pattillo & Czapla, 1997). During flood tides *B. patronus* is present in the upper layer of the water column to maximized transport into estuarine habitat. During recruitment events in April, as it was the case during my study, water surface current were influenced by strong easterly winds. This wind pattern would facilitate transport into nursery habitat for the larvae of *B. patronus*. On the other hand, winds originating from different quadrants have different effects on the zooplankton community. For instance, strong northerly winds associated with cold front passages drastically decrease water level in wetlands. In such instance, the mostly sessile *M. mitchelli* enters the water column in order to avoid being exposed to open air on mudflats (Appendix IV-D). Major peaks in *R. harrisii* also happened during April and august 2010, April 2011 and April-May 2013. Each pulse happened at time of strong south eastern winds (Appendix IV-E). When exposed to different rates of hydrostatic pressures, *R. harrisii'*s behavioral response will vary accordingly. An increase in hydrostatic pressure at full tide will induce an ascend response whereas a decrease in hydrostatic pressure at ebb tide will induce a descent (Forward , 2009). Thus, the increased number of specimens collected, in the upper part of the water column during my study, can be related to an increase in hydrostatic pressure caused by a full tide event during a period of strong easterly winds at the Rigolets Pass. The aforementioned species are the most likely to display a strong response to wind driven tides due to their life requirements. Because of their mostly benthic life style, *Gammarus spp, Edotea montosa, Argulus spp.* and copepods were most likely present in the water column due to an increase in water level and consequent increased wave action in usually protected habitat (Appendix IV-F,G,H,I). Subsequently, advection occurred thus explaining their presence in the sample but in relatively low numbers.

Conclusion

In trying to better understand the factors contributing to both spatial and temporal differences in the zooplankton communities at the three inlets locations, it became clear that all abiotic and biotic variables used to run my analyses were all interconnected. Some of the species present at the three sites are capable to withstand various types of environmental conditions associated with estuarine habitats. Importantly, all species are interdependent and the predator/prey interactions occur at various developmental stages. It also became clear that, many of the species collected throughout my study, undergo nocturnal diel vertical migration. Consequently, the results of this study might just offer a very simplistic view of the community composition at the tidal inlets. Furthermore, another important aspect of zooplankton communities is their distribution throughout the water column. Positioning in the water column vary from one species to another or even within the same species but at different developmental stages. The various positioning in the water column can be the results of either movement from one habitat to another, foraging and/or reproductive behavior. In order to better assess the zooplankton community in future research, it will be necessary to take into consideration the numerous and different ecological and biological aspects of the species making up the estuarine zooplankton community. Although the results of this study might not accurately represent the zooplankton community, it provides a glimpse into the life history of the many species collected at the three tidal inlet connecting Lake Pontchartrain to the Gulf of Mexico. Finally, the results of this study might serve as a baseline for future research in zooplankton community composition around Lake Pontchartrain.

Chapter 2

Zooplankton organisms in a tidal inlet setting: Their occurrences, life histories, and responses to potential threats

Introduction

As the seventh largest delta in the world, the Louisiana coastal wetlands contain about 37 percent of the herbaceous marshes in the conterminous United States. These wetlands provide natural protections from flooding and erosion to coastal communities and act as a natural sink for carbon (Couvillion, *et al*., 2011). Economically, the wetlands provide habitat for 75 percent of the national fisheries catch and generate an estimated $12 billion to $47 billion annually in natural resources and services (Khalil and Raynie, 2015). For close to a century, the Louisiana coastal wetlands have been experiencing severe erosion accounting for 90 percent of the wetland loss in the United States. From the 1930s to 2014, about 23 percent of Louisiana coastal wetlands converted to open water (Turner, *et al.*, 2016). Off the Louisiana coast, lie the barrier islands, some of which are experiencing rates of erosion in the order of 20m/yr. These barrier islands play a crucial role in protecting the estuary and wetlands from the marine environment (Williams, *et al.*, 1997). The occurrence of major hurricanes, such as Katrina, Rita, Gustave, and Ike, in a relatively short period of time (2005-2008), resulted in a net loss of 210,000 acres of land which was equivalent to many decades of coastal land loss (Barras, 2009). The 2010 Deepwater Horizon Oil Spill, which released more than 4.9 million barrels of oil, reached about 1055 km of shoreline in the Gulf of Mexico and resulted in accelerated rates of erosion in some impacted areas (Turner, *et al.*, 2016). Furthermore, the dredging of canals to access oil and gas locations and the creation of spoil banks, mainly by the petroleum industry, altered the natural hydrology and sedimentation patterns causing an increase in wetlands loss (Bass and Turner, 1997). In order to protect lives and property as flooding becomes more prevalent in the future, there will be pressure to construct more flood protection structures in Louisiana.

Lake Pontchartrain is connected to the Gulf of Mexico via three passes. The tidal amplitude ranges from 3 to 45 cm and water movement within the lake is primarily induced by wind forcing (McCorquodale and Georgiou, 2004). Prior to the closure of the MRGO in 2009 the tidal exchange through the passes was as follows: the Rigolets Pass 64%, Chef Menteur Pass 30% and the Inner Harbor Navigational Canal 6% (Haralampides, 2000). To the south, at Seabrook, the Inner Harbor Navigational Canal connects Lake Pontchartrain to the Intracoastal Waterway and Lake Borgne. The construction of the Inner Harbor Navigational Canal was approved in 1914, started in 1918 and was completed in 1923 when the canal was finally open to the Mississippi River traffic. It was not until 1942 that the Inner Harbor Navigational Canal was connected to the Gulf Intracoastal Waterway (USACE, 1997). In addition, the USACE started the construction Mississippi River Gulf Outlet in 1958 to provide a deep draft shipping channel from the Gulf of Mexico to the Inner Harbor Navigational Canal and subsequently to New Orleans. The MRGO was completed and open to traffic in 1968. However, the MRGO was closed to navigation in 2009 due to its deleterious impact on the adjacent marsh and because it contributed to the storm surge from Hurricane Katrina which eventually flooded New Orleans (Poirrier, 2013). To the East, Chef Menteur Pass is a natural inlet connecting Lake Pontchartrain to Lake Borgne. The Pass has a total length of 10.3km, an average depth of 12.5m and a cross sectional area of 3,660m^2. The tidal marshes along Chef Menteur Pass are intermediate and contain both fresh water and brackish water plant species. In terms of habitat, the marsh areas directly adjacent to Chef Menteur Pass provide both diversity and complexity to many organisms. To the North East, the Rigolets Pass is the largest inlet of the three. It has a total length of 8.5 miles, an average depth of 10.3m, and an average cross sectional area of 7,636m^2 thus it making the bigger pass of the two natural tidal inlets (Lopez, *et al.*, 2011). The Rigolets Pass is bordered by freshwater and intermediate marsh to its north and intermediate marsh to its south (EPA map). Similarly to Chef Menteur Pass, this area offers more diverse and complex habitats than the heavily urbanized area where the Inner Harbor Navigational Canal connects to Lake Pontchartrain at Seabrook. These passes are utilized by numerous organisms to move in and out Lake Pontchartrain at various stages of their life cycles.

The alteration of the Lower Mississippi Delta has negatively impacted the coastal wetland in Louisiana. Subsequently, nearly 1.2 million acres have been loss to land erosion during the last 80 years (Khalil and Raynie, 2015). In order to prevent further land loss, an important protection and restoration plan, the Louisiana's Comprehensive Master Plan for a Sustainable Coast was implemented in 2007 (CPRA, 2007). This plan aims at restoring critical coastal wetlands features and to sustain them, as well as protecting endangered ecosystems. This master plan is revised every 5 years as per Louisiana state law. Various strategies, with an emphasis on sediment management and import of new sand to the coastal system, were chosen. The dominant projects include marsh creation, barrier island restoration, and sediment diversions along with the integration of hurricane protection systems (Khalil and Raynie, 2015).

In the 2017 Master plan, a structural protection project, the Lake Pontchartrain Barrier, would consist of closure gates and weirs that will be constructed across the Rigolets Pass and Chef Menteur Passes in order to reduce the risk of storm surge within the Lake Pontchartrain Basin. In addition, a closure gate for navigation and multiple vertical lift gates to maintain tidal exchange will be built at each pass (CPRA, 2017). The first Lake Pontchartrain barrier project was approved by congress in 1965, the same year that Hurricane Betsy made landfall in

Louisiana in September. The storm surge overtopped the then existing Chalmette back levee, the Inner Harbor Navigational Canal levees, and the Citrus and New Orleans East back levee causing widespread damage (USACE, 1967). The initial project was met with fierce opposition from various local groups who feared that navigation on Lake Pontchartrain would be negatively impacted and that the potential for flooding on the north shore would likely increase when the barrier would close. More importantly, the greater concern was with the possibility of environmental adverse effects. In 1975, the adequacy of the project Environment Impact Statement (EIS) was challenged and was later found to not meet the National Environmental Policy Act (NEPA). Finally in 1977, an injunction was issued on further construction of the Lake Pontchartrain Barrier project (Wooley and Shabman, 2007). Such structures typically interfere with the natural migratory routes of important estuarine dependent species which utilize natural passes to move in and out the estuary.

Darnell (1962) estimated that over three hundred species of fishes and invertebrates inhabit Lake Pontchartrain at various stages of their life cycles. For instance, many estuarine-dependent species such as White Trout (*Cynoscion arenarius*), Striped Mullet (*Mugil cephalus*), Red Drum (*Sciaenops ocellatus)*, White Shrimp (*Litopenaeus setiferus*), Brown Shrimp (*Farfantepenaeus aztecus*) and Blue Crab (*Callinectes sapidus*) need to have access to Lake Pontchartrain in order to complete their life cycles. Other species including the endangered Loggerhead Sea Turtle (*Caretta caretta*), West Indian Manatee (*Tricherus* manatus) move in and out of the Lake at various times during the year (Cope, 2013).

The life cycle of the *F. aztecus* starts offshore where it spawns. Hatching occurs in early spring and late summer. As the swimming larvae goes through several molts it moves to estuarine nursery habitats by taking advantages of inshore currents. Once brown shrimp postlarvae reach suitable habitats, such as SAV beds and emergent marshes, they will settle and develop into an adult. Similarly, white shrimp spawn offshore and recruit back into estuarine nursery habitat but at a later time during the year (O'Connell, *et al.*, 2005). Another commercially important and estuarine dependent species is the blue crab. This species of portunid crab has a different life cycle than the aforementioned penaeid shrimp species. Following mating in lower salinity waters, the female moves into higher salinity areas, on the fringe of the estuary where it releases its eggs. The newly hatched zoeas undergo further development on the continental shelf and will subsequently recruit back into the estuary once the megalopae stage is reached. Finally, the megalopae will molt into a juvenile crab and continue moving up estuary into a shallower and less saline environment (O'Connell,*et al.*, 2005; Millikin and Williams, 1984).

In order to assess potential impacts of flood barriers on migratory species in Lake Pontchartrain, pre-disturbance baseline data on the occurrence and composition of zooplankton are necessary. Such studies have been conducted in various estuaries. From 2006 to 2009, in the Mondego Estuary, Portugal, a monitoring program took place in order to measure the effects of various mitigations measures on the zooplankton communities and compare the results to a pre-existing database (Falcao, *et al*., 2012). The study showed that zooplankton communities did respond to the enhanced water circulation by an increase in density and a homogenization of the downstream communities when compared to a pre-existing dataset (Falcao, *et al*., 2012). Similarly, in the lower Clarence River system of south-eastern Australia, a study was conducted in order to describe the differences between habitats affected and unaffected by flood mitigation structures with an emphasis on the ecological effects on estuarine and freshwater communities in the lower Clarence River system (Pollard and Hannan, 1994). The results of the study showed that the overall quality of fish habitat decreased with the increasing land used activities which are greater with flood mitigation work. It was suggested that the management of the floodgates should consist in keeping the gates open at all time, except in the event of a storm, in order to improve flushing and water quality, resulting in the conservation of critical nursery habitats (Pollard and Hannan, 1994).

Therefore the purpose of my research was:

1. To determine which species were present in the passes into Lake Pontchartrain;
2. To describe their life history such that their ability to withstand future impacts can be assessed; and
3. Generate photographic images of these species to aid future researcher studying the biota of the passes.

Material and methods

Larval tows were performed during the strongest flowing tide period of the month. The tows were completed in triplicate, with three SeaGear “Bongo” nets (500 µ mesh size, attached to 1 m diameter hoops) towed simultaneously at the water surface for ten minutes across the width of the pass (perpendicular to the incoming tide) in order to cover as much of the pass as possible. Collected samples were preserved on-board with 10% Rose Bengal-dyed buffered formalin solution. The samples were then processed in the lab, utilizing a 250 µ sieve and stored in a 70% ethanol solution. They were then sorted and identified taxonomically to the lowest level possible using multiple book sources (Johnson and Allen, 2005; Johnson and Allen, 2012; Thorp and Covitch, 2001; Felder and Griffis, 1994; Voshell, 2002; Schultz, 1969).

Species

Rhithropanopeus harrisii

Kingdom:	Animalia
Phylum:	Arthropoda
Subphylum:	Crustacea
Class:	Malacostraca
Order	Decapoda
Infraorder:	Brachyura
Family:	Panopeidae
Genus:	***Rhithropanopeus***
Species:	***harrisii***

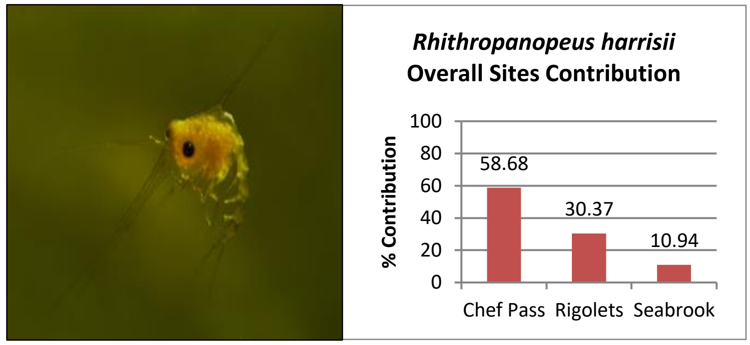


Figure 11. Scientific classification, picture, and overall sites contribution of *Rhithropanopeus harrisii.*

Occurrence

During sampling156,816 zoeas of *R.harrisii* were collected at the three sites making this particular species the most abundant species collected representing 89.22% of the overall abundance. More than half of *R. harrisii* zoeas were collected at Chef Menteur Pass. For this species temporal distribution generally consists of two peaks in abundance in a given year, the first one occurring in April-May and the second one occurring in August -September. Around the world, *R. harrisii* is among one of the most widely distributed brachyuran species. It is listed has a nonindigenous species in 21 countries. This species of crab is native from the East coast of North America where it inhabits fresh to brackish waters, from New Brunswick, Canada, to Veracruz, Gulf of Mexico. It was accidently introduced into the San Francisco Bay via translocation of the Atlantic Oyster (*Crassostrea virginica*) from the Chesapeake Bay in an attempt to start oyster aquaculture (Roche and Torchin, 2007). Populations of *R.harrisii* were also reported in 10 freshwater impoundments in Texas (Boyle and Keith, 2010). This species was first described in Europe, more precisely in the Netherlands, as a native species, *Pilumnus* *tridentus*, during the first half of the 20th century. The cause of introduction, in various parts of the world, is accredited to ships discharging their ballast water despite regulations (Roche and Torchin, 2007).

Biology and Ecology

It has been determined that *R.harrisii* is a euryhaline and eurythermal crab which can be found in water salinity ranging from 0.5 to 41 and in water temperature ranging from 1°C to 34.1°C (Costlow, 1966). Although, it is found in a wide range of salinity, *R.harrisii* reproductive areas are limited by the presence of the rhizocephalan parasite *Loxothylaxus panopei*. This species is an endoparasite which invades the host as a female cypris larva causing sterilization in both male and female crab hosts. The parasite survives well at salinities ranging from 10 to 15 but does poorly at salinities below 10 and at 20. This provides *R.harrisii* with a reproductive refuge below 10 (Reisser and Forward, 1991; Forward, 2009).

Females of *R. harrisii* spawn from spring to fall in the middle Atlantic coast and the species is thought to spawn during most of the year in southern waters (Johnson and Allen, 2005). Females, in temperate warm water, are capable of spawning multiple times during a breeding season. They are capable of laying eggs as early as three days after copulation. Eggs clutch size can vary from 1, 280 to 4,800 eggs and reach up to 15,000 to 16,000 eggs per clutch for the larger female specimens. Multiple spawnings during a breeding season could be a better reproductive strategy as it allows for *R.harrisii* to disperse temporally and thus increase the number of surviving offspring. *R.harrisii* larvae pass through four zoeal stages and a postlarval stage before metamorphosing into a juvenile (Forward, 2009).

Potential Responses to Threats

As one of the most widely distributed crab species globally, *R. harrisii* is a highly successful invasive species. Adults have low environmental factors requirements thus facilitating the establishment of population in various type of habitat ranging from the cold Baltic and North Sea, to low salinity areas in North and Central America, and more recently in fresh water reservoirs in Texas (Forward, 2009). The construction of the flood gates at Chef Menteur Pass and the Rigolets Pass are not likely to interfere with the life cycle of *R. harrisii*. In the event of a storm, the closure of the floodgates would likely result in an increase in salinity on the storm surge side of the floodgate and a decrease in salinity on the Lake side of the floodgate. Although *R.harrisii* has an optimum range of environmental conditions at 20-25 ºC and 15-20 , this species of xanthid crab has been observed in salinity ranging from 0.5 to 41 (Forward, 2009). Additionally, gravid females of *R. harrisii* were collected in the Possum Kingdom Fresh water Reservoir, Texas, in order to study the hatching success rate over a salinity ranging from 0.5 to 15. This study showed that, indeed, a high percentage of eggs did successfully hatch when exposed to various salinities (Boyle and Keith, 2010).

Argulus spp

Kingdom:	Animalia
Phylum:	Arthropoda
Subphylum:	Crustacea
Class:	Maxillopoda
Subclass:	Branchiura
Order:	Arguloida
Family:	Argulidae
Genus:	*Argulus*
Species:	*spp*

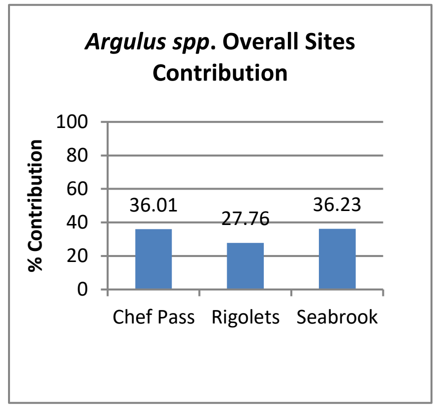


Figure 12. Scientific classification, picture, and overall sites contribution of *Argulus spp.*

Occurrence

The overall abundance and of *Argulus spp.* was equal to 1% with a total of 1,758 specimens collected at the three locations. Chef Menteur Pass and Seabrook had a similar contribution to the overall abundance, 36.01% and 36.26% respectively, and the Rigolets contributed the less to the overall abundance with 27.76%. *Argulus spp.* were present in subsequent numbers starting in early spring throughout late fall. Peek abundances for this particular species occurred during the warmer summer months. The subclass Branchiura comprises a single family the Argulidae. There are four genera in the Argulidae family: *Argulus, Chonopeltis, Dipteropeltis, and Dolops*. The four genera are geographically distributed as follow: *Dipteropeltis* occurs in South America, Chonopeltis is only found in Africa, and *Dolops* is primarily found in South America but also in Tasmania and in parts of Africa. The species of the three previously mentioned genera only occur in freshwater. *Argulus* is the most widely distributed of the four genera. It is present on all the continents with the exception of

Antarctica and occurs in both marine and estuarine habitats (Poly, 2008). *Argulus* contains 129 valid species out of which seven species were described from sites within the Gulf of Mexico and a total of 10 species (*A.alosae, A.bicolor, A.floridensis, A.funduli, A.fuscus, A.laticauda, A.megalops, A.rotundus, A.varians, and A.yucatanus*) were reported. The first Argulid to be described from the Gulf of Mexico, *Argulus funduli* was collected in near New Orleans (Poly, 2009).

Biology and Ecology

Argulus spp are obligate ectoparasites causing argulosis, a disease resulting in the reduced growth and survival of their hosts. Contrarily to many aquatic parasites, they retain their ability to swim throughout their entire life. The capability to freely swim from hatching to spawning is a minimum requirement to find viable hosts and ultimately mate but also an important one as it helps maintaining population integrity. The life cycle of *Argulus spp.* requires them to remain in restricted areas where fishes are in high abundance. This is important at the beginning of their life cycle when metanauplii hatch and need to rapidly find a host where it will grow to an adult. Although juveniles are strongly attached they may abandon their host to find a mate or a more suitable host. After mating on a host fish, females swim from the host to lay their eggs in distinct monolayer patterns using an adhesive substance. Females produce multiple clutches each containing several hundred eggs. The location of egg laying is related to the habitat use by specific host fish. Various types of substrates ranging from stones to vegetation are used depending on the species (Poly, 2009; Mikheev, *et al.*, 2015).

Potential Responses to Threats

The life cycle of the members of the *Argulus* genus is very similar with the exception of the developmental stages between hatching and maturity. *Argulus spp.* do not require a specific host in order to feed. In Europe, *A. foliaceus, A. coregoni* and *A. japonicas* show very low specificity in which fish species they parasite. Instead, host choice depends on the combination of both the presence or absence of certain species and the prevailing environmental conditions (Walker, 2008). Although, *Argulus spp.* rarely impact natural fish populations, epizootic can happen when a natural equilibrium has been perturbed by anthropogenic actions. The closure of the floodgates could be considered such an action. On the Lake side of the flood gate, fishes that generally move in and out of Lake Pontchartrain would suddenly find themselves trapped. This situation would in turn be beneficial for *Argulus spp.* as increased population densities would facilitate parasites transmission resulting in deleterious effect on the fish's immune system (Walker, 2008).

Penaeid shrimp (*Litopenaeus setiferus* and *Farfantepenaeus aztecus*)

Kingdom:	Animalia
Phylum:	Arthropoda
Subphylum:	Crustacea
Class:	Malacostraca
Order	Decapoda
Suborder:	Dendrobranchiata
Family:	Penaeidae

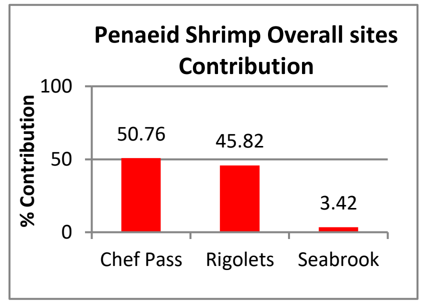


Figure 13. Scientific classification, picture, and overall sites contribution of penaeid shrimp

Occurrence

Penaeid shrimp represented 0.86% of the overall abundance and 1,519 specimens were collected during the duration of the study. Chef Menteur Pass and the Rigolets contributed the most to the overall abundance with 50.76% and 45.82% respectively. Seabrook contributed the least to the overall penaeid shrimp abundance with 3.42%. There were two seasonal peaks in abundance, the first one occurring in April-May and the second one occurring in August-September. There are 56 species of Penaeid shrimp occurring in the Gulf of Mexico (Felder,*et al.*, 2009). For this part of my thesis, I will primarily describe the species that are the most common as adults in the tidal passes of Lake Pontchartrain and the surrounding marshes, *Litopenaeus setiferus* and *Farfantepenaeus aztecus*. The larvae of these species are difficult to identify and some key elements such as seasonal occurrence, species 'range and habitat were used to narrow the species down to two.

Biology and Ecology

Litopenaeus setiferus

White shrimp (*Litopenaeus setiferus*) occur from Virginia to Florida on the East coast and throughout the GOM. In the Gulf of Mexico, their spawning season starts in March and last through September. A female can produce from 500,000 to 1,000,000 eggs in one spawning event (Anderson, *et al.*, 1949). The larval development requires from two to three weeks. 24 hours after the egg is spawned the first nauplius stage emerges. The larval development consists of 10 distinct stages including five nauplius stages, three protozoa stages, and two mysis forms. *L.setiferus* spawn closer to the shore than other commercial shrimp and the larval development lasts from 10 to 12 days. The postlarvae migrate farther into low salinity areas then *Farfantepenaeus aztecus* and settles in beds of submersed aquatic vegetation (Johnson & Allen, 2005).

Farfantepenaeus aztecus

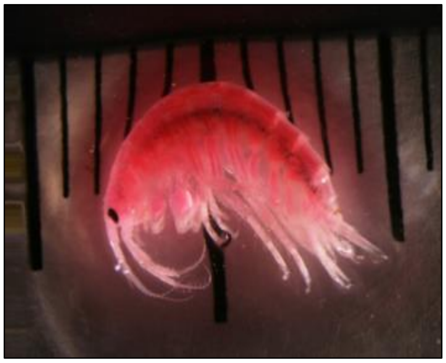
Brown Shrimp (*Farfantepenaeus aztecus*) occurs from Virginia to Florida and on the northern and western Gulf of Mexico. In the northwestern part of the Gulf, the larvae and postlarvae of *F.aztecus* overwinter in the water of the continental shelf and recruit into the estuaries the following spring. The larval development is very similar to *L.setiferus* with the exception of an additional third mysis stage for *F.aztecus* compared to two for *L.setiferus* (Cook and Lindner, 1967).

Potential Responses to Threats

Both brown and white shrimp species are estuarine-dependent species and as so they both utilize Lake Pontchartrain for part of their life cycle. During the course of their migration back to the estuary, both penaeid shrimp species utilize selective tidal stream transport or STST. Storm surge can also play an important role in facilitating transport toward the estuary as it was the case in 2008 when hurricanes Gustave and Ike carried juvenile shrimp into Lake Pontchartrain (Lopez, *et al.*, 2011). Closed flood structures at the tidal inlets would negatively impact recruitment into the Lake. This in return would adversely impact both commercial and recreational fisheries, as well as Lake Pontchartrain food chain by considerably limiting the amount of shrimp recruiting back into the Lake.

Gammarus spp.

Kingdom:	Animalia
Phylum:	Arthropoda
Subphylum:	Crustacea
Class:	malacostraca
Order	Amphipoda
Suborder:	Senticaudata
Family:	Gammaridae
Genus:	*Gammarus*
Species:	*spp*



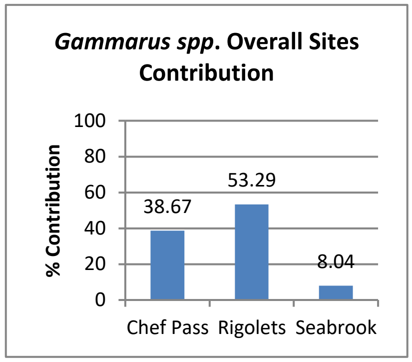


Figure 14. Scientific classification, picture, and overall sites contribution of *Gammarus spp*.

Occurrence

During this study, 1,368 *Gammarus spp* were collected, representing 0.78% of the overall species abundance. *Gammarus mucronatus* occurs in coastal and estuarine environment from the Gulf of St. Lawrence in southeastern Canada to southern Florida and the Gulf coast states (Johnson and Allen, 2005). It also occurs in California where it was introduced in 1957 when specimens of the marine grass *Diplanthera wighti* were brought from Texas to the Salton Sea by the California department of Fish and Game (Barnard and Gray, 1968).

G. mucronatus is euryhaline and generally found in shallow bays and tidal pools. Its preferred habitats consist of SAV, widgeon grass, turtle grass and submerged marsh grass. In the oligohaline regions of the upper bays and river mouths, *G. mucronatus* is replaced by another species which can be identified by its strongly developed mucronations which is referred to as macromucronations. Mucronations are sharp, posteriorly directed, dorsal processes on the first three abdominal segments. This species, *Gammarus lecroyae*, was first described in 2009 (Thoma and Heard, 2009). Finally, a third species of *Gammarus* lacking mucronation and more similar to *Gammarus tigrinus*, is commonly found in lower salinities in tidally influenced freshwater regions (Heard, 1982).

Biology and Ecology

In many communities, *Gammarus spp.* plays an important role in the trophic dynamic. From breaking down plant material and detritus to filter feeding and scavenging they are an important key part of the diet of many species of fish (LeCroy, *et al.*, 2009). Most of the common species have breeding seasons lasting for six to ten months a year but some populations were found to breed throughout the year. These reproductive periods usually have one or two peaks phases where multiple generations of sexually mature females are produced, resulting in multiple broods of young. The occurrences of the reproductive cycles are based on local environmental conditions such as temperature and salinity. Furthermore, resting periods, defined here as when the female stop ovulating, are influenced by a decrease in daylight which limits the number of broods produced in a year. Breeding activities usually increase during the late winter and early spring due to the availability of food supplies. After mating, the female undergoes ecdysis and eggs are laid through two ventral pores into a thoracic sternite. A greater number of eggs, up to 200, are common in epifaunal species but not in infaunal species. Mature eggs will then hatch into juveniles resembling the adult and will be held in the brood pouch for a few hours to a few days (Grosse and pauley, 1986)

Potential Responses to Threats

In general, *Gammarus spp.* occurs in tidal marsh pools and SAV. The presence of *Gammarus spp.* in the collected samples throughout the study was primarily due to advection forces, such as tidal currents during ebb and full tides, causing specimens to be removed from the shallow water habitat on the shorelines of tidal inlets. The closure of the flood gate during a storm event could prove itself to be detrimental to population of *Gammarus spp.* located on the storm surge side. The increase in water level and, wave action on the marsh directly situated along the flood structure could cause the entire community to be removed from their normally shallow water habitat.

Cerapus tubularis

Kingdom:	Animalia
Phylum:	Arthropoda
Subphylum:	Crustacea
Class:	Malacostraca
Order	Amphipoda
Suborder:	Senticaudata
Family:	Ischyroceridae
Genus:	*Cerapus*
Species:	*tubularis*

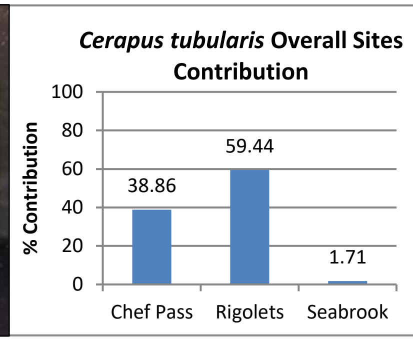


Figure 15. Scientific classification, picture, and overall sites contribution of *Cerapus tubularis*

Occurrence

A total of 1,346 specimens of *Cerapus tubularis* representing 0.77% of the total species abundance were collected. *C. tubularis* occurs from Cape Cod to eastern Florida, Texas, Laguna de Tamiahua and Punta del Gada, Mexico, Laguna Madre, Tamaulipas, Mexico, Laguna Alvarado, Veracruz, Mexico, Cuba, Brazil, and Ria Deseado, Argentina

Biology and ecology

Like all peracarids, *C. tubularis* broods its eggs in a marsupium. This tube dwelling amphipod is found in fouling communities, seagrass beds, on muddy sand bottoms and channels on the East Coast of the U.S. In Texas, *C. tubularis* attached to subtidal rocks, algae and oyster reefs in low energy habitats. In Cuba, *C. tubularis* was found at depth of 20 m on algae (Lecroy, 1997). *C. tubularis* has been reported from depth of 1to 30 meters but it is more common at depth shallower than 10 m (Dickinson and Wigley, 1980). This tube dweller is often found in area of high current flow. Large mats of intertwined tubes can also be found on muddy or silty bottom. The construction and composition of the tube differs from one species to another and usually consists of pieces of algae or detritus. *Cerapus spp.* can swim up into the water column by emerging halfway from their tube and by strongly beating their antennae

Potential Responses to Threats

This particular species of amphipod has the capability to attach itself on various types of substrates including both natural and artificial material and in low and high energy habitats. In some aspects, the construction of the flood structure might create a new habitat for this species of amphipod with low environmental requirements. Finally, in the event of s storm, established communities of *C. tubularis* located on the storm surge side of the floodgates could also be removed from the area due to an increase in wave energy.

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Macoma mitchelli

Kingdom:	Animalia
Phylum:	Mollusca
Class	Bivalvia
Order:	Veneroida
Family:	Tellinidae
Genus:	*Macoma*
Species:	*mitchelli*

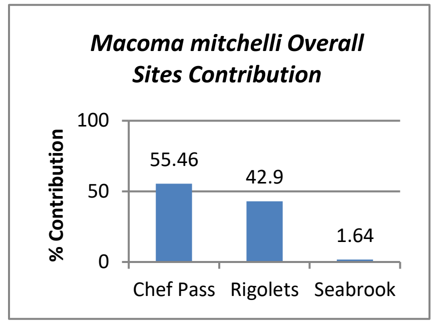

Figure 16. Scientific classification, picture, and overall sites contribution of *Macoma mitchelli*

Occurrence

A total of 1,098 *Macoma mitchelli* specimens were collected during the study, contributing to 0.68% of the overall species abundance. *M. mitchelli* is a burrowing tellenid bivalve found along the Atlantic and Gulf Coast of the United States in mesohaline to polyhaline water (Kennedy and Lutz, 1989)

Biology and ecology

Following fertilization, it takes about 12 hours or less for the egg to develop into the planktonic trocophore larva. The ciliated larva feeds on suspended particles for a few hours before it develops into the veliger larva. At this stage the larva remains suspended in the water column for one to five weeks and feeds on phytoplankton. Locomotion is typically accomplished by drifting in the water column using long trailing byssal or mucous threads. Following this stage, the veliger transforms into a bivalve form known as the pediveliger which will settle on the substrate and become a juvenile (Baker and Mann, 1997). Laboratory studies have indicated that veliger of *Macoma spp.* are capable of active depth regulation and respond to changes in temperature, salinity and pressure. The younger veliger have higher upward swimming speeds than sinking speeds which helps maintain their position near the surface resulting in downstream transport. On the contrary, the later veliger stages are more abundant near the bottom either due to physical forcing, or both behavioral and physiological changes. In a partially to well-mixed estuary, the late stage veliger, when maintaining their position near the bottom, experience a net upstream transport due to high salinity water input at the estuary mouth (Garrison and Morgan, 1999). This dispersal and recruitment strategy allows for early developmental stages of many species to avoid higher rate of predation in upstream habitats.

Potential Responses to Threats

In the advent of a storm and the subsequent closure of the floodgates, Lake Pontchartrain would remain cut off from the Gulf of Mexico for an extended period of time. This would decrease local salinity, increase nutrient load, and could potentially create a situation where algal blooms, similar to the one observed during the 1997 opening of the Bonnet Carre Spillway, occur in the Lake. This type of bloom creates hypoxic or anoxic conditions due to the decomposition of dead algae. These conditions would create a dead zone where established *M. mitchilli* communities would experience great rate of mortality.

Edotea montosa

Kingdom:	Animalia
Phylum:	Arthropoda
Subphylum:	Crustacea
Class:	Malacostraca
Order	Isopoda
Suborder:	Valvifera
Family:	Idoteidae
Genus:	*Edotea*
Species:	*montosa*

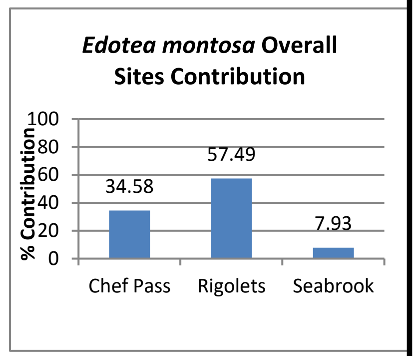

Figure 17. Scientific classification, picture, and overall sites contribution of *Edotea montosa*.

Occurrence

During the study, 668 *Edotea montosa* were collected, representing 0.62% of the overall species abundance. *E. montosa* ranges from Massachusetts to Florida and in the eastern Gulf of Mexico. *E. montosa* occurs in the swash zone along the beach to 10 km offshore. It is also present in bays and creeks (Johnson and Allen, 2005).

Biology and ecology

Young of E. montosa are brooded in a ventral pouched, the marsupium. Brood size ranges from four to five young to hundreds depending on the species. The post embryonic stage known as the manca is similar to the adults but lacks the last pair of pereopods. The mancae molt a few times and the juvenile will become adult. Most littoral species studied appear to have a life span of one to two years (Brusca and Iverson, 1985).

Potential Responses to Threats

As a grazer, *E. montos*a primary threat due to the construction of various flooding structures, in the short term, would be the direct loss of habitats and more importantly of potential food sources. In the long term, this ubiquitous species of isopod would probably not be drastically impacted as it does not require very specific environmental requirements.

Copepods

Kingdom:	Animalia
Phylum:	Arthropoda
Subphylum:	Crustacea
Class:	Maxillopoda
Subclass:	Copepoda
Order:	Calanoida, Cyclpoida, Harpacticoida

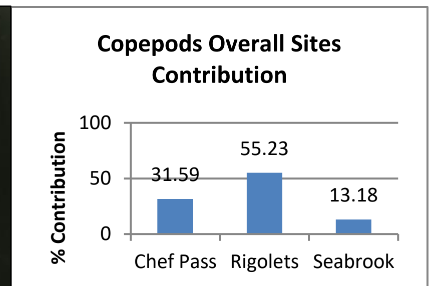

Figure 18. Scientific classification, picture, and overall sites contribution of copepods

Occurrence

Copepods represented 0.25% of the overall species abundance, with 440 specimens collected during the course of the study. These microcrustaceans are widely distributed worldwide and occur mainly in marine and freshwater environments but also in terrestrial and semiterrestrial habitats (Suarez-Morales, *et al.*, 2009). This group of crustaceans contains more than 200 families and more than 10,000 species. They are considered to be the most abundant animals on the planet. During the study four groups were identified: the calanoid, cyclopoid, harpacticoid and siphonostomatoid groups.

Biology and ecology

The vast majority of copepods reproduce sexually and a single fertilization can result in multiple clutches. The fertilized eggs can either be released in the water or attached to the female in egg clusters. After the eggs hatch the larvae go through six naupliar stages followed by five copepodid stages. After each molts, body segments and pairs of legs are added to the copepodids which slowly become to resemble the adults. Copepod life spans last from six months to a year. Copepods play an important role in marine food chains by acting as an important link between primary production and higher trophic levels. They are a major component of the microbial loop by preying upon bacterioplankton and heterotrophic protists and they serve as prey for ichthyoplankton and other pelagic carnivores (Turner, 2004).

Potential Responses to Threats

With a sudden increase in nutrient loading in the Lake, a subsequent phytoplankton proliferation would likely occur. Initially, the increase in organic material might be beneficial for the copepod grazing community as it would provide more food. On the other hand, if grazing rates by copepods are less than rates of phytoplankton production, an excessive built up in organic matter, in the water column, would result in an increased rate of sedimentation on the Lake floor. The reduced level of oxygen could prevent eggs that are resting on the Lake floor to hatch but also reduce their viability (Marcus, 2004). Finally, because hypoxia and anoxia occur at the sediment-water interface, copepods might be pushed up in the water column where they would be exposed to potential predators thus increasing their mortality rates (Breitburg, *et al.*, 1997). Copepods are an important component of any pelagic food web. A decrease in both the nauplius and adult stages, a key component to many fish larvae diet developing in inshore nursery habitats, could have a catastrophic effect on the viability of Lake Pontchartrain food chain.

Americamysis almyra

Kingdom:	Animalia
Phylum:	Arthropoda
Subphylum:	Crustacea
Class:	Malacostraca
Subclass:	Eumalacostraca
Order:	Mysida
Family:	Mysidae
Genus:	*Americamysis*
Species:	*almyra*

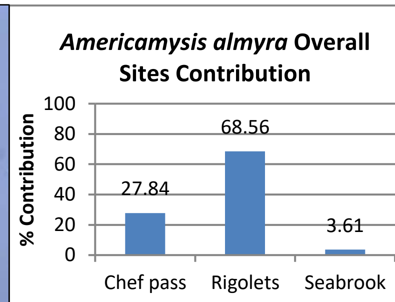

Figure 19. Scientific classification, picture, and overall sites contribution of *Americamysis almyra*.

Occurrence

With 388 specimens collected during the study, Americamysis *almyra* represented 0.22% of the overall species abundance. *A. almyra* occurs from Maryland to Florida and throughout the Gulf. It is regularly collected in grass beds and shallow marshes areas in salinity ranging from 0 to 32 (Johnson and Allen, 2005).

Biology and ecology

Similarly to amphipods and isopods, A. *almyra* broods its young in a ventral pouch. The brood size is dependent upon the size of the female and can vary from 4 to 15 young per clutch (Price, 1978). The mysids once released are almost fully developed and closely resemble the adult stage. In temperate climate, overwintering specimens released their young in spring and in warmer waters specimens might reproduce year round (Johnson and Allen, 2005). As an omnivorous species, its diet consists of small algae and detritus particles along with, smaller living zooplankton (Johnson and Allen, 2005). Mysids are an important diet item in the young specimens of *A. mitchilli*, *C. arenarius* and *M. undulatus* (Bowman, 1964).

Potential Responses to Threats

As a euryhaline species *A. almyra* can be found in salinity ranging from 0 in Alligator Lake Texas to 55 in Baffin Bay Texas (Price, 1978). In Lake Pontchartrain, this particular species of mysid shrimp was found to be markedly abundant and it was found in salinities ranging from 1.2 to 18.6 (Darnell, 1958). Thus, the closure of the floodgate and the potential change in salinity would not negatively affect this particular species. In the event of a hypoxic or anoxic event, *A. almyra* has the capability to swim away from low water quality. An advantage of this particular species is its reproductive mode. As a brooder, the juvenile can also be move to an adequate habitat without risking the loss of future generations.

Daphnia spp.

Kingdom:	Animalia
Phylum:	Arthropoda
Subphylum:	Crustacea
Class:	Branchiopoda
Order:	Cladocera
Family:	Daphnidae
Genus:	*Daphnia*
Species:	*spp*

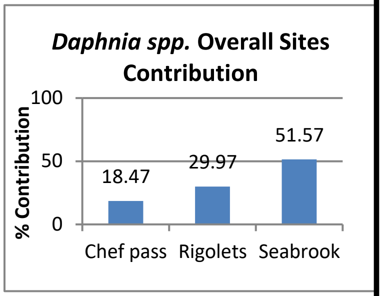

Figure 20. Scientific classification, picture, and overall sites contribution of *Daphnia spp.*

Occurrence

During this study, 287 specimens were collected and represented 0.16% of the overall species contribution. *Daphnia spp.* occurs in all freshwater habitats ranging from small ponds to large lakes, streams and rivers (Dodson and Frey, 2001).

Biology and ecology

Females of *Daphnia spp.* exhibit cyclical parthenogenesis where more females are produced when environmental conditions are favorable. A brood is produced every time the females molt every three to four days. A given brood can contain up to 100 eggs. The eggs are placed in a brood chamber which is located under the carapace. The eggs undergo direct development. The embryos hatch from the eggs after one day and the young stay in the brood chamber for an additional three days before being released. Juveniles of *Daphnia spp.* pass through four to six instars before they become mature females. When environmental conditions are less favorable sexual reproduction is favored. The resulting fertilized eggs, encased in a protective coating called an ephippium, sink to the bottom where they will rest until the conditions are once again favorable. *Daphnia spp.* occupy an important position in aquatic communities as both grazers and prey items for fish and other aquatic predators (Johnson and Allen, 2005; Dodson and Frey, 2001).

Potential Responses to Threats

The construction of flood structures would not likely impact *Daphnia spp.* It is an ubiquitous organism capable of living in various environment. Daphnids were observed in Lake Oberer Arosasee, Switzerland, in low oxygen concentrations layers and also anoxic layers suggesting that they are highly tolerant to oxygen deficiency (Winder, *et al.*, 2003). A study conducted in Lake Grafenhain, Germany, demonstrated that two species of *Daphnia*, *Daphnia pulex* and *Daphnia rosea*, were able to produce haemoglobin in order to colonize low oxygen layers. This physiological adaptation allows *D. pulex* and *D. rosea* to exploit food resources and avoid predation by planktivorous fish in a low oxygen environment (Sell, 1998). Similar to copepods, the initial increase in primary production by nutrient loading in Lake Pontchartrain might be beneficial to *Daphnia spp*. as its food resource would drastically increase.

Caligus spp.

Kingdom:	Animalia
Phylum:	Arthropoda
Subphylum:	Crustacea
Class:	Maxillopoda
Subclass:	Copepoda
Order:	Siphonostomatoida
Family:	Caligidae
Genus:	*Caligus*
Species:	*spp*

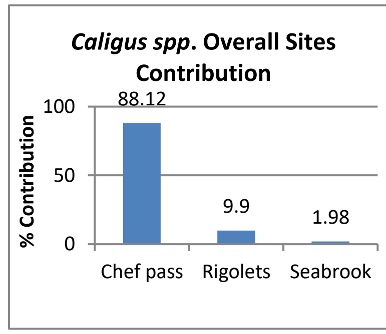

Figure 21. Scientific classification, picture, and overall sites contribution of *Caligus spp.*

Occurrence

The overall species abundance of *Caligus spp.* was 0.06% with 101 specimens collected during this study. The marine genus *Caligus* is one of the most widely distributed group of parasitic copepod. It comprises about 200 species worldwide with only one freshwater species, *Caligus lacustris,* reported. In the Gulf of Mexico and western Caribbean Sea, 26 species have been identified (Suarez-Morales, *et al.*, 1997). Typically, *Caligus spp.* occur in high salinity embayments and their presence in brackish water could be explained by fishes migrating from higher salinity water to lower salinity water as part of their life requirements (Johnson and Allen, 2005).

Biology and Ecology

The life cycle of C*aligus spp.* includes eight to ten developmental stages depending on the species. The gravid females produce a series of egg strings which give rise to two nauplius stages, followed by a copepodid stage. The three aforementioned stages are all free living planktonic stages. Once the copepodid stage is reached, settlement on a host fish occurs and *Caligus spp.* will go through two chalimus and two preadult stages before becoming an adult (Boxaspen, 2006; Igboeli, *et al.*, 2014). *Caligus spp*. is an ectoparasite which becomes infective during the copepodid stage. This parasitic copepod feeds on the mucus and epidermal tissue of the host fish which causes serious skin infections.

Potential Responses to Threats

As a marine parasitic copepod, *Caligus spp.* would be negatively impacted by a decrease in water salinity around Lake Pontchartrain. Adult sea lice die rapidly at salinities below 12 and even though eggs can hatch in salinities as low as 15 their chance of survival remains low. Increases in salinity rates to values reaching 20 to 25 could somewhat improve this species chances of survival. Furthermore, the infective copepodid stage of sea lice does not fare well in salinity below 30 (Brooks, 2005). Lake Pontchartrain's salinity range is not favorable for the dispersion of *Caligus spp.* The fluctuations in salinity, in the lower range, resulting from the closure of the floodgates at the tidal inlets, would prove to be detrimental to this particular ectoparasite and thus beneficial to Lake Pontchartrain fish assemblages.

Lepidophthalmus louisianensis

Kingdom:	Animalia
Phylum:	Arthropoda
Subphylum:	Crustacea
Class:	malacostraca
Order:	Decapoda
Family:	Callianassidae
Genus:	*Lepidophthalmus*
Species:	*louisianensis*

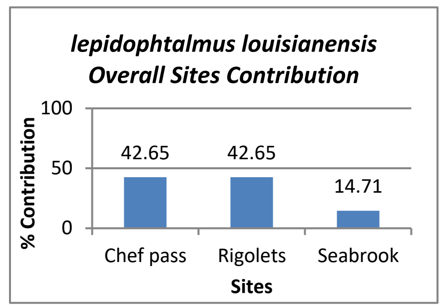

Figure 22. Scientific classification, picture, and overall sites contribution of *Lepidophthalmus louisianensis*

Occurrence

During the course of this study, 68 specimens were collected, representing 0.04 of the overall species abundance. The callianassid shrimp species *Lepidophthalmus louisianensis* occurs in intertidal and shallow subtidal areas of the northern part of the Gulf of Mexico (Johnson and Allen, 2005).

Biology and ecology

The location, timing and frequency of mating have been difficult to observe in *L. louisianensis* and mating was suggested to happen in intersecting burrows. The reproductive cycle include two or three annual peaks in ovarian development in February, May and July resulting in winter, summer and fall recruitment events (Felder and Griffis, 1994). In parental females of L. *louisianensis* the average number of eggs is 598. The eggs are carried by the female for a period of 25 to 30 days. There are four developmental sequences in *L. louisianensis*: a prezoea, two zoeas and a decapodid stage or postlarvae (Nates, *et al*. 1997). The larval stage is short only lasting 36 to 48 hours. The rapid development of juvenile also suggests that specimens settle into the sediment soon after reaching the decapodid stage. *L. louisianensis* is thought to play an important role in sediment turnover and to influence macrobiotic and microbiotic communities by adding large amounts of burrow wall surface area beneath the sediment surface. This increase in surface area as for effects to promotes nutrients exchange between the sediments and the benthic community (Felder and Griffis, 1994).

Potential Responses to Threats

Most of the specimens of *L. louisianensis* were collected at the two natural tidal inlets. Chef Menteur pass and the Rigolets pass, both offer intertidal and subtidal soft sediments habitats necessary for the propagation of this particular thalassinid shrimp species. The rapid development stage of both the larvae and postlarvae suggest that individuals reenter the sediment quickly after reaching the decapodid stage, thus showing that local recruitment of population is an important aspect of their ecology (Felder and Griffis, 1994). The loss of habitats due to the construction of the floodgates and other associated structures would result in the loss of local population of *L. louisianensis* for an unknown period of time. Bioturbation associated with burrowing increases oxygenation and mineralization of sediments, therefore a decrease in in population of *L. louisianensis* would results in a drop in habitat quality furthermore impacting species benefiting their presence.

Livoneca redmanii

Kingdom:	Animalia
Phylum:	Arthropoda
Subphylum:	Crustacea
Class:	Malacostraca
Order:	Isopoda
Family:	Cymothoidae
Genus:	*Livoneca*
Species:	*redmanii*

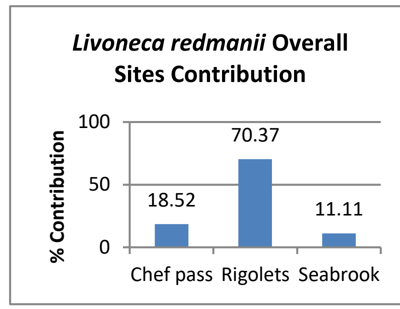

Figure 23. Scientific classification, picture, and overall sites contribution of *Livoneca redmanii*

Occurrence

A total of 27 specimens, representing 0.02% of the overall species abundance, were collected during this study. Cymothoid isopods occur in all oceans with the exception of polar waters. They are primarily marine with a limited presence in African, Asian and South American freshwater systems (Smit, *et al.*, 2014). *Livoneca redmanii* occurs from Massachusetts to Florida and in the Gulf of Mexico west of Mississippi in both coastal and estuarine waters (Johnson and Allen, 2005).

Biology and ecology

Cymothoid isopods, such as *L. redmanii*, are hematophagous, protandrous hermaphrodites. Free living *L. redmanii* tend to be living near the shore where hosts are readily available. Once this parasitic isopod attaches to its host it positions itself on a specific site such as the buccal cavity, branchial cavity or body cavity. The first male to parasite a fish converts to a female. The remaining males do not convert to a female due to pheromone and neurohormone released by the female. The number of eggs carried by a gravid female in the marsupium ranges from 300 to 600 eggs. There are at least three juvenile instars following the manca stage. The juveniles are referred to as aegathoid and they resemble the adult male (Brusca, 1978; Neeraja, *et al.*, 2014).

Potential Responses to Threats

This parasitic isopod will not likely be impacted by the floodgates and the subsequent increase or decrease in salinity. Although, some species show a preference in host onto which they would complete part of their reproductive life cycle, it is not necessary to its survival. The manca stage can, for a period of time, attach and feed on another host species, drop off, and molt into a natatory-stage known as aegathoid (Jones, *et al.*, 2008).

Polychaete worm

Kingdom:	Animalia
Phylum:	Annelida
Class:	Polychaeta

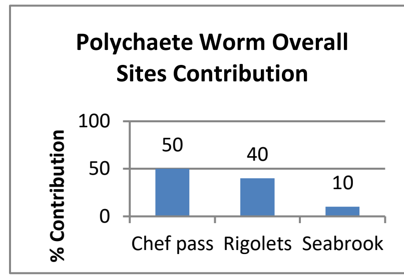

Figure 24. Scientific classification, picture, and overall sites contribution of *polychaete worm.*

Occurrence

Few specimens (10), representing 0.01% of the overall species abundance, were collected during the study. Polychaetes are present in all environments ranging from intertidal pools to the depth of the oceans and even free swimming in open water (Johnson and Allen, 2005)

Biology and ecology

Three families of benthic polychaetes (Nereidae, Syllidae and Eunicidae) enter the plankton for mating during large aggregations at the surface where they increase fertilization success through synchronous spawning. This particular phase of sexual maturation is referred to as epitoky. Larval polychaetes develop through three stages. The trocophore, a ciliated larva, is usually pelagic. During the metatrocophore stage, two to three segments have formed and the larva is either planktotrophic or lecitotrophic. The most advanced larval stage is called the nectochaete stage during which the larva may not be longer pelagic. Once settled, depending on the species, the larva may go through a benthic stage called the erpochaete stage or become a juvenile (Crumin, 2001). Polychaetes are an important component in food chains where they are part of the diets of shrimp, crabs, fishes, and also birds.

Potential Responses to Threats

Polychaete worms are tolerant to a wide range of environmental parameters. Interestingly, environmental perturbations such as hypoxia play an important role in exposing benthic macrofauna to predation. Low dissolved oxygen levels cause polychaetes to move to the surface of the sediment surface in order to reach area with greater dissolved oxygen concentrations. In doing so, they expose themselves to benthic feeding fishes such as Spot (*Leiostomus xanthurus*) and Atlantic Croaker (*Micropogonias undulatus)* which can feed for a short period of time in low oxygen environments (Bosch, 2014). Thus, a probable hypoxic event associated with a sudden increase in nutrient and a poor water circulation within Lake Pontchartrain has the capability to impact the polychaete benthic assemblage by creating a habitat squeeze situation where, in addition to increase predation a depth due to exposure, demersal fish are moving to shallower oxygenated water furthermore intensifying predation on adjacent areas (Kemp and Boynton, 1981). A sudden decrease in polychaete worms would be problematic as they are an important key component in promoting nutrient balance through bioturbation in the Lake Pontchartrain benthic ecosystem.

Cystobranchus vividus

Kingdom:	Animalia
Phylum:	Annelida
Class:	Clitellata
Subclass:	Hirudinea
Order:	Rhynchobdellida
Family:	Piscicolidae
Genus:	*Cystobranchus*
Species:	*vividus*

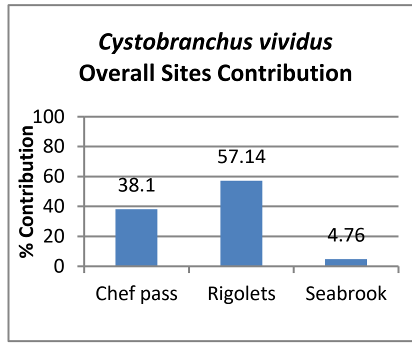

Figure 25. Scientific classification, picture, and overall sites contribution of *Cystobranchus vividus*.

Occurrence

During the course of this study, 21 specimens, representing 0.01% of the overall species abundance, were collected. *Cystobranchus vividus* occurs from Massachusetts to the Gulf of Mexico (Johnson and Allen, 2005).

Biology and ecology

Leeches are hermaphroditic. Cross fertilization does still occur between two leeches. The clitellum, a non-segmented section of the body, located near the head of the leech, secretes a cocoon into which one fertilized egg is deposited. The cocoon is attached to the substrate. The newly hatched immature individuals measure about 3.0 millimeters and are somewhat similar to a mature adult. Immature leeches swim immediately to find their favored host. *C. vividus* occurs on various hosts from blue crabs to fishes and displays a seasonal occurrence. *C. vividus* are abundant in late February and early March before they become rare from April until December (Johnson and Allen, 2005; Sawyer and Hammond, 1973)

Potential Responses to Threats

As a true marine invertebrate, *C. vividus* tolerates a wide range of salinities. In a laboratory experiment, specimens were taken from water with salinity of 28 to be exposed to salinity of 0, 1.62, 3.24, 6.48, 12.19 25.58. The results showed that *C. vividus* could successfully withstand drastic changes in salinity (Sawyer and Hammond, 1973). Temperature is probably the most important factor in controlling the presence and absence of *C. vividus* as it displays a seasonal occurrence. The leeches are the most numerous, during their known breeding season, between the month of December and March, when the lowest water temperatures are typically recorded. No leeches are present during the rest of the year (Sawyer and Hammond, 1973). In the case of the closure of the floodgates, populations of *C. vividus* would not likely be negatively impacted as its natural occurrence is outside of any potential tropical storm season.

Lucifer faxoni

Kingdom:	Animalia
Phylum:	Arthropoda
Subphylum:	Crustacea
Class:	Malacostraca
Order:	Decapoda
Suborder:	Dendrobranchiata
Family:	Luciferidae
Genus:	*Lucifer*
Species:	*faxoni*

Figure 26. Scientific classification, picture, of *Lucifer faxoni.*

Occurrence

Only one specimen was collected during the entire duration of the study. *Lucifer faxoni* occurs from Rhode Island to Texas. This species of Sergestid shrimp is common in salinities as low as 16 but it prefers salinity around 30 (Johnson and Allen, 2005).

Biology and ecology

Female of *L. faxoni* produces up to 140 eggs over a lifetime in multiple broods. Unlike most penaeid shrimp which shed their eggs directly in the water, *L. faxoni* attaches its eggs to the third walking leg until nauplii hatch. There are two or more nauplius stages, three protozoea, two zoeas and up to two postlarval stages (Miyako, *et al.*, 1996; Santos & Lindley, 2001). *L. faxoni* is an important component of the coastal ecosystem and is a key component in the diet of numerous fishes.

Potential Responses to Threats

Specimens of *L. faxoni* are found in the neritic zone and it is seldom found in areas similar to the tidal inlets connecting Lake Pontchartrain to the Gulf of Mexico. The only specimen collected during the course of this study was in the Rigolets Pass. Its presence in this tidal inlet was probably due to strong onshore currents. Thus, the floodgates will not likely impact this species since it is typically not found in the Rigolets Pass or Chef Menteur Pass.

Discussion

As a result of increased human population, environment quality in coastal areas is rapidly declining, thus eroding biological diversity and ecosystem functions (Duarte, *et al.,* 2008). The potential construction of alternative flood control structures on Chef Menteur and Rigolets Passes will undeniably impact the zooplankton communities at both the small and large scales (Appendix V). All the proposed flood structures would have embankments, gates with piers and sills associated with their construction, resulting in flood constriction. Estimates of the Rigolets Pass channel reduction with the structure open ranges from 72% to 29% of the cross sectional area. The estimates for Chef Menteur Pass range from 72% to 39% reduction of the cross sectional area (Lopez, *et al.,* 2011). The cross sectional restriction would result in increased flow velocity which could be detrimental to estuarine dependent species with weak swimming capabilities.

The numerous species found at the three passes were somewhat similar with some slight variances in the communities' composition at each inlet. When assessing the main species collected throughout this study, the majority are primarily part of the meroplankton and therefore only present in the water column as part of their life requirement. Specimens collected during this study are present throughout the year, in the passes or directly in the adjacent intermediate or freshwater marshes. The reason for presence and absence of some of the species are due to their life cycles and ecology. Inshore zooplankton communities consist of deep and shallow water species which vary depending on the season and the environmental conditions. Both meroplankton and holoplankton undergo different vertical migration patterns. It is usually accepted that there are multiple recognized patterns in migration. The most common one consist on an evening ascent and a morning descent but there is also a twilight reverse, a tidal and a semi-diel migration pattern (Rawlinson, *et al.*, 2004). These movement patterns are different among species but also among ontogenetic stages among a given species. For instance, normally benthic, specimens of polychaete worms were only collected in the form of epitoke which is their reproductive form. *Macoma mitchelli* was only present in the samples during the colder months when water levels are typically at their lowest. This could be a behavioral trait resulting in an escape response mechanism induced by a sharp drop in hydrostatic pressure associated with a frontal passage. This would result in *M. mitchelli* entering the water column to avoid being exposed to increased predation on exposed mudflats. *Gammarus spp.*is a benthic species which feed on detritus was also present in low numbers. The aforementioned species can reach high density in their respective benthic habitat but can seldom be found in the water column as part of their ecology.

Even though, all the species collected throughout the duration of the study are important at various ecological levels, commercially and recreationally important species of penaeid shrimp species, *F. aztecus* and *L. setiferus*, are both vital to the local seafood industry. In addition to their economic value, both species play an important role in the ecosystem as prey items for many fish species but also as nutrient recyclers. These two species of penaeid shrimp were collected primarily at Rigolets and Chef Menteur Passes. As estuarine dependent species, brown and white shrimp utilize estuarine habitat to increase their survivorship by avoiding predation and accessing increased food sources (O'Connell, *et al.*, 2005). They are only present at certain time of the year and both have a different temporal distribution. In the case of the brown shrimp recruitment to the estuarine environment occurs in spring and into the summer and occurs in summer and fall for white shrimp. Like many estuarine dependent species, brown and white shrimp utilize selective tidal stream transport in order to reach adequate habitats through tidal inlets. The cross sectional restriction of both natural tidal inlets could negatively affect both larval and juvenile transport in and out Lake Pontchartrain due to an increase in flow velocity. Another important point is the time of occurrence of white shrimp. As previously stated, white shrimp typical season is during the summer and into fall. The closure of the flood gate would most likely be during the peak of hurricane season, during late summer and early fall. The potential closing of the floodgates during a recruitment event would prove highly detrimental for the white shrimp fishery and could have long lasting effects on future generations.

Conclusions

Specimens collected were only partly representative of the zooplankton community at the three sites. In order to better assess both meroplankton and holoplankton communities at different depths, time of the day but also multiple sizes of specimens, various sampling techniques require simultaneous applications. In addition, sampling of shallow water habitats adjacent to the two natural water inlets could help understand the existing connectivity between shallow and pelagic zones and how full tide and ebb tide affect the zooplankton community and what their response might be.

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Appendix I

Similarity percentage analysis showing dissimilarities between each pairwise month's combinations. Species are ranked in decreasing order based upon their contribution to dissimilarities.

1) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between September and October and across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis September & October (Average Dissimilarity = 57.98)				
Species	Average Density (m^3) September	Average Density (m^3) October	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.99	0.32	28.53	49.20
Penaeid Shrimp	0.13	0.06	5.58	9.62
Argulus spp.	0.14	0.07	4.50	7.76
Cerapus tubularis	0.05	0.05	3.88	6.69
Megalopae	0.09	0.02	3.80	6.56
Gammarus spp.	0.07	0.03	2.56	4.42
Larval fishes	0.04	0.02	1.87	3.22
Edotia montosa	0.04	0.01	1.82	3.14

2) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between September and November and across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis September & November (Average Dissimilarity = 84.28)				
Species	Average Density (m^3) September	Average Density (m^3) November	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.99	0.05	48.38	57.41
Argulus spp.	0.14	0.10	7.24	8.59
Penaeid Shrimp	0.13	0.00	6.01	7.13
Megalopae	0.09	0.00	3.76	4.46
Gammarus spp.	0.07	0.05	3.73	4.42
Cerapus tubularis	0.05	0.01	2.84	3.37
Americamysis almyra	0.02	0.03	2.29	2.72
Larval fishes	0.04	0.01	1.81	2.15

3) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between October and November and across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis October & November (Average Dissimilarity = 78.55)				
Species	Average Density (m^3) October	Average Density (m^3) November	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.32	0.05	31.37	39.94
Argulus spp.	0.07	0.10	12.02	15.30
Penaeid Shrimp	0.06	0.00	7.55	9.61
Gammarus spp.	0.03	0.05	6.85	8.72
Cerapus tubularis	0.05	0.01	6.35	8.09
Larval Fishes	0.02	0.01	2.65	3.37
Livoneca redmanii	0.01	0.01	2.50	3.18
Americamysis almyra	0.00	0.03	2.29	2.92

4) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between September and December across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis September & December (Average Dissimilarity = 92.73)				
Species	Average Density (m^3) September	Average Density (m^3) December	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.99	0.00	50.13	54.06
Argulus spp.	0.14	0.02	6.67	7.20
Penaeid Shrimp	0.13	0.00	6.07	6.54
Copepod	0.02	0.07	4.46	4.81
Gammarus spp.	0.07	0.06	4.20	4.53
Megalopae	0.09	0.00	3.75	4.04
Cerapus tubularis	0.05	0.03	3.71	4.01
Macoma mitchelli	0.01	0.08	3.67	3.96
Americamysis almyra	0.02	0.06	2.57	2.77

5) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between October and December across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis October & December (Average Dissimilarity = 92.74)				
Species	Average Density (m^3) October	Average Density (m^3) December	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.32	0.00	31.61	34.08
Argulus spp.	0.07	0.02	8.16	8.80
Macoma mitchelli	0.00	0.08	8.05	8.68
Cerapus tubularis	0.05	0.03	7.02	7.57
Penaeid Shrimp	0.06	0.00	6.40	6.90
Copepod	0.00	0.07	6.36	6.85
Americamysis almyra	0.00	0.06	6.32	6.82
Gammarus spp.	0.03	0.06	5.86	6.32
Larval Fishes	0.02	0.02	4.17	4.49

6) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between November and December across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis November & December (Average Dissimilarity = 84.64)				
Species	Average Density (m^3) November	Average Density (m^3) December	Average Dissimilarity	Contribution %
Argulus spp.	0.10	0.02	14.28	16.87
Gammarus spp.	0.05	0.06	11.11	13.12
Macoma mitchelli	0.00	0.08	10.51	12.42
Copepod	0.02	0.07	10.03	11.85
Rhithropanopeus harrisii	0.05	0.00	9.70	11.46
Americamysis almyra	0.03	0.06	9.11	10.77
Larval fishes	0.01	0.02	5.04	5.96
Cerapus tubularis	0.01	0.03	4.65	5.50
Edotia montosa	0.00	0.03	4.08	4.83

7) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between September and January across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis September & January (Average Dissimilarity = 91.09)				
Species	Average Density (m^3) September	Average Density (m^3) January	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.99	0.01	46.56	51.11
Macoma mitchelli	0.01	0.17	7.21	7.91
Argulus spp.	0.14	0.02	5.97	6.55
Penaeid Shrimp	0.13	0.00	5.30	5.82
Gammarus spp.	0.07	0.12	4.97	5.46
Larval fishes	0.04	0.10	4.36	4.79
Megalopae	0.09	0.00	3.20	3.51
Cerapus tubularis	0.05	0.01	2.64	2.90
Edotia montosa	0.04	0.04	1.99	2.18

8) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between October and January across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis October & January (Average Dissimilarity = 92.69)				
Species	Average Density (m^3) October	Average Density (m^3) January	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.32	0.01	25.31	27.31
Macoma mitchelli	0.00	0.17	15.12	16.32
Larval fishes	0.02	0.10	8.64	9.32
Gammarus spp.	0.03	0.12	7.92	8.54
Argulus spp.	0.07	0.02	5.91	6.38
Penaeid Shrimp	0.06	0.00	5.68	6.13
Cerapus tubularis	0.05	0.01	4.32	4.66
Copepod	0.00	0.04	3.74	4.03
Cystobranchus vividus	0.00	0.06	3.73	4.02
Americamysis almyra	0.00	0.06	3.65	3.94

9) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between November and January across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis November & January (Average Dissimilarity = 87.67)				
Species	Average Density (m^3) November	Average Density (m^3) January	Average Dissimilarity	Contribution %
Macoma mitchelli	0.00	0.17	16.38	18.69
Gammarus spp.	0.05	0.12	12.01	13.69
Argulus spp.	0.10	0.02	10.72	12.23
Larval Fishes	0.01	0.10	10.39	11.85
Rhithropanopeus harrisii	0.05	0.01	9.48	10.81
Americamysis almyra	0.03	0.06	6.38	7.28
Copepod Unknown	0.01	0.03	3.83	4.36
Cystobranchus vividus	0.00	0.06	3.75	4.28
Cerapus tubularis	0.01	0.01	2.73	3.11

10) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between December and January across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis December & January (Average Dissimilarity = 75.45)				
Species	Average Density (m^3) December	Average Density (m^3) January	Average Dissimilarity	Contribution %
Macoma mitchelli	0.08	0.17	16.50	21.87
Gammarus spp.	0.06	0.12	11.83	15.68
Copepod	0.07	0.04	10.55	13.98
Larval fishes	0.02	0.10	9.21	12.21
Americamysis almyra	0.06	0.06	5.80	7.69
Cerapus tubularis	0.03	0.01	4.53	6.01
Argulus spp.	0.02	0.02	4.05	5.50
Edotia montosa	0.61	0.67	3.90	5.16
Cystobranchus vividus	0.00	0.06	3.31	4.39

11) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between September and February across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis September & February (Average Dissimilarity = 90.38)				
Species	Average Density (m^3) September	Average Density (m^3) February	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.99	0.01	43.57	48.20
Gammarus spp.	0.07	0.12	5.83	6.45
Daphnia spp.	0.00	0.10	5.24	5.80
Penaeid shrimp	0.13	0.00	4.96	5.48
Argulus spp.	0.14	0.03	4.93	5.46
Larval Fishes	0.04	0.08	4.80	5.31
Cerapus tubularis	0.05	0.06	3.81	4.21
Macoma mitchelli	0.01	0.09	3.70	4.10
Copepod	0.02	0.06	3.08	3.40
Megalopae	0.09	0.00	3.02	3.34

12) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between October and February across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis October & February (Average Dissimilarity = 86.88)				
Species	Average Density (m^3) October	Average Density (m^3) February	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.32	0.01	24.17	27.82
Gammarus spp.	0.03	0.12	9.37	10.79
Macoma mitchelli	0.00	0.09	7.73	8.89
Cerapus tubularis	0.05	0.06	7.16	8.25
Larval fishes	0.02	0.08	6.72	7.73
Daphnia spp.	0.00	0.10	6.63	7.64
Penaeid Shrimp	0.06	0.00	5.45	6.27
Copepod	0.00	0.06	5.33	6.13
Argulus spp.	0.07	0.03	4.72	5.43
Americamysis almyra	0.00	0.04	3.46	3.98

13) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between November and February across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis November & February (Average Dissimilarity = 84.63)				
Species	Average Density (m^3) November	Average Density (m^3) February	Average Dissimilarity	Contribution %
Gammarus spp.	0.05	0.12	12.09	14.29
Daphnia spp.	0.00	0.10	10.82	12.78
Argulus spp.	0.10	0.03	10.00	11.82
Larval fishes	0.01	0.08	9.23	10.91
Macoma mitchelli	0.00	0.09	8.32	10.55
Rhithropanopeus harrisii	0.05	0.01	7.16	8.46
Cerapus tubularis	0.01	0.06	7.06	8.34
Copepod	0.02	0.06	6.07	7.17
Americamysis almyra	0.03	0.04	5.09	6.01
Unknown	0.01	0.03	3.88	4.59

14) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between December and February across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis December & February (Average Dissimilarity = 77.64)				
Species	Average Density (m^3) December	Average Density (m^3) February	Average Dissimilarity	Contribution %
Gammarus spp.	0.06	0.12	11.39	14.67
Macoma mitchelli	0.08	0.09	10.47	13.48
Daphnia spp.	0.00	0.10	10.14	13.05
Copepod	0.07	0.06	9.15	11.79
Larval fishes	0.02	0.08	8.43	10.86
Cerapus tubularis	0.03	0.06	7.33	9.44
Americamysis almyra	0.06	0.04	6.97	8.98
Argulus spp.	0.02	0.03	4.13	5.32
Edotia montosa	0.03	0.01	3.14	4.04

15) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between January and February across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis January & February (Average Dissimilarity = 70.92)				
Species	Average Density (m^3) January	Average Density (m^3) February	Average Dissimilarity	Contribution %
Gammarus spp.	0.12	0.12	10.60	14.95
Daphnia spp.	0.00	0.10	10.59	14.93
Larval fishes	0.10	0.08	9.95	14.03
Macoma mitchelli	0.17	0.09	8.61	12.14
Cerapus tubularis	0.01	0.06	6.03	8.50
Copepod	0.04	0.06	5.23	7.38
Americamysis almyra	0.06	0.04	3.93	5.55
Argulus spp.	0.02	0.87	4.15	5.93
Edotia montosa	0.67	0.03	3.93	5.55
Cystobranchus vividus	0.06	0.00	3.61	5.09
Unknown	0.03	0.03	3.36	4.73

16) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between September and March across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis September & March (Average Dissimilarity = 93.38)				
Species	Average Density (m^3) September	Average Density (m^3) March	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.99	0.00	49.99	53.53
Larval fishes	0.04	0.16	9.18	9.83
Penaeid Shrimp	0.13	0.00	6.76	7.24
Argulus spp.	0.14	0.01	6.49	6.95
Megalopae	0.09	0.00	4.03	4.32
Cerapus tubularis	0.05	0.00	3.54	3.79
Gammarus spp.	0.07	0.02	2.73	2.92
Edotia montosa	0.04	0.03	2.42	2.59

17) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between October and March across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis October & March (Average Dissimilarity = 92.92)				
Species	Average Density (m^3) October	Average Density (m^3) March	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.32	0.00	31.92	34.35
Larval fishes	0.02	0.16	18.06	19.44
Argulus spp.	0.07	0.01	8.09	8.71
Cerapus tubularis	0.05	0.00	6.36	6.84
Penaeid Shrimp	0.06	0.00	6.04	0.92
Copepod	0.00	0.03	4.40	4.73
Gammarus spp.	0.03	0.02	4.38	4.72
Edotia montosa	0.01	0.03	3.53	3.80
Daphnia sp.	0.00	0.02	3.32	3.58

18) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between November and March across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis November & March (Average Dissimilarity = 91.72)				
Species	Average Density (m^3) November	Average Density (m^3) March	Average Dissimilarity	Contribution %
Larval fishes	0.01	0.16	28.11	30.64
Argulus spp.	0.10	0.01	14.50	15.81
Rhithropanopeus harrisii	0.05	0.00	10.72	11.69
Gammarus spp.	0.05	0.02	8.88	9.68
Copepod	0.02	0.03	6.06	6.61
Unknown	0.01	0.01	4.31	4.70
Edotia montosa	0.00	0.03	4.27	4.65
Daphnia spp.	0.00	0.02	3.78	4.12
Americamysis almyra	0.03	0.00	3.66	3.99

19) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between December and March across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis December & March (Average Dissimilarity = 86.07)				
Species	Average Density (m^3) December	Average Density (m^3) March	Average Dissimilarity	Contribution %
Larval fishes	0.02	0.16	23.94	27.82
Copepod	0.07	0.03	11.78	13.69
Gammarus spp.	0.06	0.02	9.65	11.21
Macoma mitchelli	0.08	0.00	9.09	10.57
Americamysis almyra	0.06	0.00	6.80	7.90
Edotia montosa	0.03	0.03	5.64	6.56
Cerapus tubularis	0.03	0.00	4.77	5.54
Argulus spp.	0.02	0.01	4.43	5.15
Daphnia spp.	0.00	0.02	3.81	4.43

20) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between January and March across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis January & March (Average Dissimilarity = 75.52)				
Species	Average Density (m^3) January	Average Density (m^3) March	Average Dissimilarity	Contribution %
Larval fishes	0.10	0.16	17.47	23.13
Macoma mitchilli	0.17	0.00	17.23	22.81
Gammarus spp.	0.12	0.02	10.81	14.32
Unknown	0.03	0.01	5.82	7.71
Edotia montosa	0.04	0.03	4.34	5.74
Americamysis almyra	0.06	0.00	3.89	5.15
Copepod	0.04	0.03	3.85	5.09
Cystobranchus vividus	0.06	0.00	3.27	4.34
Argulus spp.	0.02	0.01	2.32	3.07

21) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between February and March across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis February & March (Average Dissimilarity = 79.61)				
Species	Average Density (m^3) February	Average Density (m^3) March	Average Dissimilarity	Contribution %
Larval fishes	0.08	0.16	16.26	20.42
Gammarus spp.	0.12	0.02	11.66	14.65
Daphnia spp.	0.10	0.02	10.39	13.05
Macoma mitchelli	0.09	0.00	8.23	10.34
Copepod	0.06	0.03	7.59	9.53
Cerapus tubularis	0.06	0.00	6.93	8.71
Unknown	0.03	0.01	4.39	5.52
Americamysis almyra	0.04	0.00	4.36	5.48
Argulus spp.	0.03	0.01	3.30	4.15

22) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between September and April across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis September & April (Average Dissimilarity = 57.91)				
Species	Average Density (m^3) September	Average Density (m^3) April	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.99	3.11	32.46	56.05
Larval fishes	0.04	0.46	5.63	9.73
Penaeid Shrimp	0.13	0.26	3.15	5.44
Argulus spp.	0.14	0.13	2.67	4.61
Edotia montosa	0.04	0.17	2.62	4.52
Cerapus tubularis	0.05	0.17	2.10	3.62
Daphnia spp.	0.00	0.10	1.73	2.98
Gammarus spp.	0.07	0.13	1.68	2.91
Megalopae	0.09	0.01	1.55	2.68

23) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between October and April across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis October & April (Average Dissimilarity = 77.51)				
Species	Average Density (m^3) October	Average Density (m^3) April	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.32	3.11	48.52	62.60
Larval fishes	0.02	0.46	6.99	9.02
Penaeid Shrimp	0.06	0.26	4.96	6.40
Edotia montosa	0.01	0.17	3.24	4.18
Cerapus tubularis	0.05	0.17	2.91	3.76
Gammarus spp.	0.03	0.13	2.15	2.77
Argulus spp.	0.07	0.13	2.10	2.71

24) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between November and April across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis November & April (Average Dissimilarity = 92.41)				
Species	Average Density (m^3) November	Average Density (m^3) April	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.05	3.11	60.36	65.31
Larval fishes	0.01	0.46	6.79	7.35
Penaeid Shrimp	0.00	0.26	4.91	5.31
Edotia montosa	0.00	0.17	3.53	3.82
Argulus spp.	0.10	0.13	3.44	3.72
Gammarus spp.	0.05	0.13	2.48	2.68
Cerapus tubularis	0.01	0.17	2.42	2.62

25) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between December and April across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis December & April (Average Dissimilarity = 93.52)				
Species	Average Density (m^3) December	Average Density (m^3) April	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.00	3.11	60.32	64.50
Larval fishes	0.02	0.46	6.65	7.12
Penaeid Shrimp	0.00	0.26	4.81	5.14
Edotia montosa	0.03	0.17	3.29	3.52
Macoma mitchelli	0.08	0.07	3.04	3.26
Gammarus spp.	0.06	0.13	2.76	2.95
Cerapus tubularis	0.03	0.17	2.68	2.86
Argulus spp.	0.02	0.13	2.37	2.53

26) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between January and April across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis January & April (Average Dissimilarity = 90.27)				
Species	Average Density (m^3) January	Average Density (m^3) April	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.01	3.11	57.93	64.17
Larval fishes	0.10	0.46	5.95	6.59
Penaeid Shrimp	0.00	0.26	4.43	4.91
Macoma mitchelli	0.17	0.07	3.44	3.81
Edotia montosa	0.04	0.17	3.15	3.48
Gammarus spp.	0.12	0.13	2.86	3.16
Cerapus tubularis	0.01	0.17	2.51	2.78
Argulus spp.	0.02	0.13	2.34	2.59

27) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between February and April across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis February & April (Average Dissimilarity = 89.01)				
Species	Average Density (m³) February	Average Density (m³) April	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.01	3.11	56.74	63.75
Larval fishes	0.08	0.46	6.00	76.74
Penaeid Shrimp	0.00	0.26	4.41	4.96
Daphnia spp.	0.10	0.10	3.75	4.22
Edotia montosa	0.01	0.17	3.23	3.63
Cerapus tubularis	0.06	0.17	2.83	3.18
Gammarus spp.	0.12	0.13	2.65	2.97
Argulus spp.	0.03	0.13	2.28	2.56

28) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between March and April across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis March & April (Average Dissimilarity = 91.97)				
Species	Average Density (m³) March	Average Density (m³) April	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.00	3.11	59.65	64.86
Larval fishes	0.16	0.46	8.53	9.28
Penaeid Shrimp	0.00	0.26	5.34	5.80
Edotia montosa	0.03	0.17	3.49	3.79
Cerapus tubularis	0.00	0.17	2.69	2.92
Argulus spp.	0.01	0.13	2.30	2.51
Gammarus spp.	0.02	0.13	2.22	2.41

29) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between September and May across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis September & May (Average Dissimilarity = 51.37)				
Species	Average Density (m^3) September	Average Density (m^3) May	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.99	2.45	26.07	50.75
Argulus spp.	0.14	0.42	7.21	14.04
Edotia montosa	0.04	0.19	3.99	7.77
Penaeid Shrimp	0.13	0.10	2.93	5.70
Larval fishes	0.04	0.19	2.91	5.66
Megalopae	0.09	0.08	2.66	5.17
Cerapus tubularis	0.05	0.04	1.80	3.51

30) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between October and May across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis October & May (Average Dissimilarity = 75.27)				
Species	Average Density (m^3) October	Average Density (m^3) May	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.99	2.45	26.07	50.75
Argulus spp.	0.14	0.42	7.21	14.04
Edotia montosa	0.04	0.19	3.99	7.77
Larval fishes	0.02	0.19	3.71	4.93
Penaeid Shrimp	0.06	0.10	2.56	3.40

31) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between November and May across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis November & May (Average Dissimilarity = 89.50)				
Species	Average Density (m^3) November	Average Density (m^3) May	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.05	2.45	58.65	65.53
Argulus spp.	0.10	0.42	11.25	12.57
Edotia montosa	0.00	0.19	6.58	7.35
Larval fishes	0.01	0.19	3.50	3.91
Penaeid Shrimp	0.00	0.10	1.91	2.14

32) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between December and May across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis December & May (Average Dissimilarity = 95.48)				
Species	Average Density (m^3) December	Average Density (m^3) May	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.00	2.45	59.04	61.84
Argulus spp.	0.02	0.42	13.15	13.77
Edotia montosa	0.03	0.19	5.41	5.67
Larval fishes	0.02	0.19	3.70	3.87
Macoma Mitchelli	0.08	0.00	2.19	2.29
Copepod	0.07	0.00	2.19	2.29

33) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between January and May across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis January & May (Average Dissimilarity = 94.69)				
Species	Average Density (m^3) January	Average Density (m^3) May	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.01	2.45	53.87	56.89
Argulus spp.	0.02	0.42	11.69	12.35
Macoma Mitchelli	0.17	0.00	5.64	5.96
Larval fishes	0.10	0.19	4.90	5.17
Edotia montosa	0.04	0.19	4.87	5.14
Gammarus spp.	0.12	0.03	3.36	3.55
Penaeid Shrimp	0.00	0.10	1.83	1.93

34) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between February and May across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis February & May (Average Dissimilarity = 95.01)				
Species	Average Density (m^3) February	Average Density (m^3) May	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.01	2.45	53.64	56.46
Argulus spp.	0.03	0.42	11.23	11.82
Edotia montosa	0.01	0.19	5.06	5.32
Larval Fishes	0.08	0.19	4.75	5.00
Gammarus spp.	0.12	0.03	3.79	3.99
Macoma mitchelli	0.09	0.00	2.91	3.06
Cerapus tubularis	0.06	0.04	2.61	2.75
Daphnia spp.	0.10	0.01	2.55	2.69

35) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between March and May across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis March & May (Average Dissimilarity = 94.22)				
Species	Average Density (m^3) March	Average Density (m^3) May	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.00	2.45	58.65	62.25
Argulus spp.	0.01	0.42	12.93	13.72
Larval fishes	0.16	0.19	7.12	7.56
Edotia montosa	0.00	0.19	6.48	6.87

36) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between April and May across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis April & May (Average Dissimilarity = 50.18)				
Species	Average Density (m^3) April	Average Density (m^3) May	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	3.11	2.45	25.82	51.45
Larval fish	0.46	0.19	5.68	11.32
Argulus spp.	0.13	0.42	5.15	10.25
Penaeid Shrimp	0.26	0.10	3.04	6.06
Edotia montosa	0.17	0.19	2.33	4.64
Cerapus tubularis	0.17	0.04	2.15	4.28
Gammarus spp.	0.13	0.03	1.44	2.87

37) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between September and June across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis September & June (Average Dissimilarity = 41.75)				
Species	Average Density (m^3) September	Average Density (m^3) June	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.99	1.72	17.45	41.80
Argulus spp.	0.14	0.29	6.78	16.25
Edotia montosa	0.04	0.15	4.70	11.26
Penaeid Shrimp	0.13	0.02	2.92	7.00
Lepidophthalmus louisianensis	0.03	0.04	1.96	4.70
Megalopae	0.09	0.00	1.94	4.64
Cerapus tubularis	0.05	0.01	1.49	3.56
Larval fishes	0.04	0.05	1.46	3.50

38) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between October and June across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis October & June (Average Dissimilarity = 69.31)				
Species	Average Density (m^3) October	Average Density (m^3) June	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.32	1.72	43.69	63.03
Argulus spp.	0.07	0.29	9.36	13.51
Edotia montosa	0.01	0.15	7.17	10.34
Penaeid Shrimp	0.06	0.02	2.25	3.25

39) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between November and June across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis November & June (Average Dissimilarity = 86.13)				
Species	Average Density (m^3) November	Average Density (m^3) June	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.05	1.72	57.73	67.02
Argulus spp.	0.10	0.29	9.73	11.29
Edotia montosa	0.00	0.15	7.25	8.42
Gammarus spp.	0.05	0.02	2.10	2.44
Lepidophthalmus louisianensis	0.00	0.04	2.04	2.37

40) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between December and June across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis December & June (Average Dissimilarity = 93.95)				
Species	Average Density (m^3) December	Average Density (m^3) June	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.00	1.72	59.00	62.80
Argulus spp.	0.02	0.29	12.27	13.06
Edotia montosa	0.03	0.15	6.42	6.83
Copepod	0.07	0.01	2.98	3.17
Macoma Mitchelli	0.08	0.00	2.46	2.62
Gammarus spp.	0.06	0.02	2.42	2.57

41) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between January and June across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis January & June (Average Dissimilarity = 93.85)				
Species	Average Density (m^3) January	Average Density (m^3) June	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.01	1.72	55.96	59.62
Argulus spp.	0.02	0.29	10.91	11.62
Edotia montosa	0.04	0.15	5.53	5.90
Macoma mitchelli	0.17	0.00	5.39	5.74
Gammarus spp.	0.12	0.02	3.52	3.75
Larval fishes	0.10	0.05	3.23	3.44

42) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between February and June across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis February & June (Average Dissimilarity = 93.70)				
Species	Average Density (m^3) February	Average Density (m^3) June	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.01	1.72	53.55	57.15
Argulus spp.	0.03	0.29	9.97	10.64
Edotia montosa	0.01	0.15	5.33	5.69
Gammarus spp.	0.12	0.02	4.05	4.32
Daphnia spp.	0.10	0.00	4.01	4.28
Larval fishes	0.08	0.05	3.47	3.70
Macoma Mitchelli	0.09	0.00	2.75	2.94
Copepod	0.06	0.01	2.66	2.84

43) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between March and June across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis March & June (Average Dissimilarity = 92.80)				
Species	Average Density (m^3) March	Average Density (m^3) June	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.00	1.72	56.92	61.34
Argulus spp.	0.01	0.29	13.39	14.43
Edotia montosa	0.03	0.15	8.82	9.51
Larval Fishes	0.16	0.05	5.97	6.43

44) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between April and June across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis April & June (Average Dissimilarity = 49.38)				
Species	Average Density (m^3) April	Average Density (m^3) June	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	3.11	1.72	25.64	51.92
Larval fishes	0.46	0.05	4.86	9.85
Argulus spp.	0.13	0.29	4.41	8.93
Penaeid Shrimp	0.26	0.02	3.18	6.44
Edotia montosa	0.17	0.01	1.68	3.41
Cerapus tubularis	0.17	0.01	1.68	3.41
Daphnia spp.	0.10	0.00	1.57	3.18
Gammarus spp.	0.13	0.02	1.00	2.54

45) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between May and June across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis May & June (Average Dissimilarity = 37.05)				
Species	Average Density (m^3) May	Average Density (m^3) June	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	2.45	1.72	22.59	60.97
Argulus spp.	0.42	0.29	4.28	11.25
Larval Fishes	0.19	0.05	2.76	0.87
Edotia montosa	0.19	0.15	2.25	6.06
Penaeid Shrimp	0.10	0.02	1.44	3.90
Megalopae	0.08	0.00	1.34	3.61

46) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between September and July across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis September & July (Average Dissimilarity = 61.63)				
Species	Average Density (m^3) September	Average Density (m^3) July	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.99	0.53	34.29	55.64
Argulus spp.	0.14	0.19	6.71	10.89
Penaeid Shrimp	0.13	0.02	4.56	7.40
Megalopae	0.09	0.05	3.74	6.07
Edotia montosa	0.04	0.05	2.43	3.94
Cerapus tubularis	0.05	0.00	2.16	3.51
Gammarus spp.	0.07	0.02	1.96	3.19

47) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between October and July across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis October & July (Average Dissimilarity = 58.06)				
Species	Average Density (m^3) October	Average Density (m^3) July	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.32	0.53	23.97	41.29
Argulus spp.	0.07	0.19	7.83	13.49
Megalopae	0.02	0.05	5.68	9.79
Penaeid Shrimp	0.06	0.02	5.01	8.64
Cerapus tubularis	0.05	0.00	4.50	7.75
Edotia montosa	0.01	0.05	3.20	5.50
Gammarus spp.	0.03	0.02	3.04	5.23

48) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between November and July across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis November & July (Average Dissimilarity = 76.08)				
Species	Average Density (m^3) November	Average Density (m^3) July	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.05	0.53	29.2	38.39
Argulus spp.	0.10	0.19	17.79	23.39
Gammarus spp.	0.05	0.02	6.12	8.05
Edotia montosa	0.00	0.82	5.16	6.79
Megalopae	0.00	0.05	4.24	5.57
Unknown	0.01	0.02	3.72	3.07
Americamysis almyra	0.03	0.00	2.16	2.84
Penaeid Shrimp	0.00	0.02	1.94	2.55

49) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between December and July across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis December & July (Average Dissimilarity = 91.45)				
Species	Average Density (m^3) December	Average Density (m^3) July	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.00	0.53	30.47	33.32
Argulus spp.	0.02	0.19	17.18	18.78
Macoma mitchelli	0.08	0.00	7.20	7.87
Copepod	0.07	0.01	5.93	6.48
Edotia montosa	0.03	0.05	5.86	6.41
Americamysis almyra	0.06	0.00	5.63	6.15
Gammarus spp.	0.06	0.02	5.06	5.54
Megalopae	0.00	0.05	4.64	5.07
Cerapus tubularis	0.03	0.00	2.62	2.86

50) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between January and July across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis January & July (Average Dissimilarity = 91.97)				
Species	Average Density (m^3) January	Average Density (m^3) July	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.01	0.53	25.06	27.25
Argulus spp.	0.02	0.19	16.49	17.93
Macoma mitchelli	0.17	0.00	12.65	13.75
Larval fishes	0.10	0.00	7.54	8.20
Gammarus spp.	0.12	0.02	6.97	7.58
Edotia montosa	0.04	0.05	5.23	5.68
Copepod	0.04	0.01	3.33	3.62
Cystobranchus vividus	0.06	0.00	3.28	3.57
Unknown	0.03	0.02	3.18	3.46

51) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between February and July across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis February & July (Average Dissimilarity = 88.59)				
Species	Average Density (m^3) February	Average Density (m^3) July	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.01	0.53	24.36	27.49
Argulus spp.	0.03	0.19	13.30	15.01
Gammarus spp.	0.12	0.02	8.21	9.27
Daphnia spp.	0.10	0.00	6.82	7.70
Macoma mitchelli	0.09	0.00	6.64	7.49
Larval fishes	0.08	0.00	6.04	6.82
Cerapus tubularis	0.06	0.00	4.88	5.51
Copepod	0.06	0.01	4.38	4.95
Unknown	0.03	0.02	3.75	4.23
Edotia montosa	0.01	0.05	3.33	3.76

52) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between March and July across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis March & July (Average Dissimilarity = 94.26)				
Species	Average Density (m^3) March	Average Density (m^3) July	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.00	0.53	33.01	35.02
Larval fishes	0.16	0.00	17.16	18.20
Argulus spp.	0.01	0.19	16.73	17.75
Megalopae	0.00	0.05	6.38	6.76
Edotia montosa	0.03	0.05	4.82	5.12
Copepod	0.03	0.01	3.94	4.18
Gammarus spp.	0.02	0.02	3.40	3.61

53) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between April and July across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis April & July (Average Dissimilarity = 77.49)				
Species	Average Density (m^3) April	Average Density (m^3) July	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	3.11	0.53	48.52	62.62
Larval fishes	0.46	0.00	6.29	8.12
Penaeid Shrimp	0.26	0.02	4.26	5.50
Argulus spp.	0.13	0.19	3.95	5.09
Edotia montosa	0.17	0.05	3.19	4.12
Cerapus tubularis	0.17	0.00	2.26	2.92
Gammarus spp.	0.13	0.02	1.77	2.29

54) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between May and July across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis May & July (Average Dissimilarity = 66.58)				
Species	Average Density (m^3) May	Average Density (m^3) July	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	2.45	0.53	45.05	67.66
Argulus spp.	0.42	0.19	7.65	11.49
Edotia montosa	0.19	0.05	4.29	6.44
Larval fishes	0.19	0.00	3.10	4.66

55) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between June and July across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis June & July (Average Dissimilarity = 64.41)				
Species	Average Density (m^3) June	Average Density (m^3) July	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	1.72	0.53	44.64	69.31
Argulus spp.	0.29	0.19	7.37	11.44
Edotia montosa	0.15	0.05	4.74	7.36
Megalopae	0.00	0.82	2.07	3.31

56) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between September and August across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis September & August (Average Dissimilarity = 42.35)				
Species	Average Density (m^3) September	Average Density (m^3) August	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.99	0.90	19.12	45.14
Argulus spp.	0.14	0.14	4.80	11.33
Penaeid Shrimp	0.13	0.10	3.37	7.97
Larval Fishes	0.04	0.13	2.54	6.01
Megalopae	0.09	0.03	2.52	5.94
Gammarus spp.	0.07	0.05	2.46	5.80
Copepod	0.02	0.09	1.78	4.21
Cerapus tubularis	0.05	0.01	1.11	2.63
Lepidophthalmus louisianensis	0.03	0.02	1.01	2.39

57) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between October and August across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis October & August (Average Dissimilarity = 57.18)				
Species	Average Density (m^3) October	Average Density (m^3) August	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.32	0.90	28.71	50.22
Penaeid Shrimp	0.06	0.10	6.83	11.94
Larval Fishes	0.02	0.13	6.23	10.89
Copepod	0.00	0.09	3.59	6.28
Argulus spp.	0.07	0.14	2.91	5.09
Cerapus tubularis	0.05	0.01	2.26	3.95
Gammarus spp.	0.03	0.05	1.84	3.22

58) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between November and August across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis November & August (Average Dissimilarity = 78.46)				
Species	Average Density (m^3) November	Average Density (m^3) August	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.05	0.90	42.58	54.27
Argulus spp.	0.10	0.14	8.05	10.26
Gammarus spp.	0.05	0.05	4.92	6.27
Larval Fishes	0.01	0.13	4.20	5.35
Penaeid Shrimp	0.00	0.10	3.92	4.99
Copepod	0.02	0.09	3.58	4.56
Americamysis almyra	0.03	0.01	2.30	2.93
Megalopae	0.00	0.03	1.90	2.42

59) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between December and August across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis December & August (Average Dissimilarity = 85.52)				
Species	Average Density (m^3) December	Average Density (m^3) August	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.00	0.90	43.16	50.47
Argulus spp.	0.02	0.14	7.98	9.34
Copepod	0.07	0.09	7.10	8.30
Gammarus spp.	0.06	0.05	4.88	5.70
Macoma mitchelli	0.08	0.01	4.58	5.36
Larval Fishes	0.02	0.13	4.33	5.06
Penaeid Shrimp	0.00	0.10	3.36	3.92
Cerapus tubularis	0.03	0.01	2.81	3.28

60) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between January and August across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis January & August (Average Dissimilarity = 86.11)				
Species	Average Density (m^3) January	Average Density (m^3) August	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.01	0.90	45.87	53.26
Argulus spp.	0.02	0.14	10.26	11.92
Gammarus spp.	0.12	0.05	5.29	6.15
Larval Fishes	0.10	0.13	4.47	5.19
Macoma mitchelli	0.17	0.01	4.23	4.91
Penaeid Shrimp	0.00	0.10	3.24	3.77
Copepod	0.04	0.09	2.20	2.55
Cerapus tubularis	0.01	0.01	2.08	2.41

61) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between February and August across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis February & August (Average Dissimilarity = 86.47)				
Species	Average Density (m^3) February	Average Density (m^3) August	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.01	0.90	41.78	48.32
Daphnia spp.	0.10	0.00	7.89	9.13
Argulus spp.	0.03	0.14	7.29	8.44
Larval Fishes	0.08	0.13	7.09	8.20
Gammarus spp.	0.12	0.05	4.10	4.74
Copepod	0.06	0.09	3.42	3.96
Penaeid Shrimp	0.00	0.10	3.24	3.75
Cerapus tubularis	0.06	0.01	2.59	3.00
Macoma mitchelli	0.09	0.01	2.27	2.62

62) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between March and August across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis March & August (Average Dissimilarity = 90.09)				
Species	Average Density (m^3) March	Average Density (m^3) August	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.00	0.90	47.35	52.55
Larval fishes	0.16	0.13	12.67	14.07
Argulus spp.	0.01	0.14	11.31	12.56
Penaeid Shrimp	0.00	0.10	3.56	3.95
Gammarus spp.	0.02	0.05	3.41	3.79
Edotia montosa	0.03	0.03	2.10	2.33
Unknown	0.01	0.00	1.95	2.16

63) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between April and August across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis April & August (Average Dissimilarity = 61.59)				
Species	Average Density (m^3) April	Average Density (m^3) August	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	3.11	0.90	40.93	66.45
Larval fishes	0.46	0.13	3.14	5.11
Argulus spp.	0.13	0.14	2.88	4.68
Edotia montosa	0.17	0.03	2.43	3.95
Daphnia spp.	0.10	0.00	2.36	3.83
Penaeid Shrimp	0.26	0.10	2.13	3.46
Cerapus tubularis	0.17	0.01	1.51	2.45
Gammarus spp.	0.13	0.05	1.49	2.42

64) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between May and August across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

SIMPER Analysis May & August (Average Dissimilarity = 54.39)				
Species	Average Density (m^3) May	Average Density (m^3) August	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	2.45	0.90	30.63	56.31
Argulus spp.	0.42	0.14	8.65	15.90
Larval fishes	0.19	0.13	3.51	6.46
Edotia montosa	0.19	0.03	2.97	5.47
Penaeid Shrimp	0.10	0.10	2.41	4.42
Megalopae	0.08	0.03	1.97	3.62

65) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between June and August across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

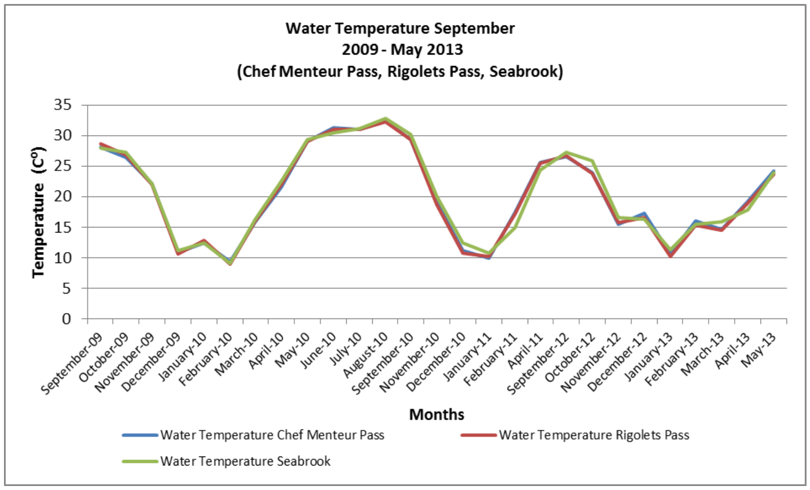
SIMPER Analysis June & August (Average Dissimilarity = 51.37)				
Species	Average Density (m^3) June	Average Density (m^3) August	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	1.72	0.90	31.99	62.27
Argulus spp.	0.29	0.14	6.21	12.08
Larval Fishes	0.05	0.13	2.74	5.34
Lepidophthalmus louisianensis	0.04	0.02	2.26	4.39
Penaeid Shrimp	0.02	0.10	1.78	3.47
Edotia montosa	0.15	0.03	1.76	3.43

66) Similarity Percentage (SIMPER) only showing the species that contributes up to 90% of the differences between July and August across all the sites. The contribution % indicates how much a species contributed to the overall dissimilarities.

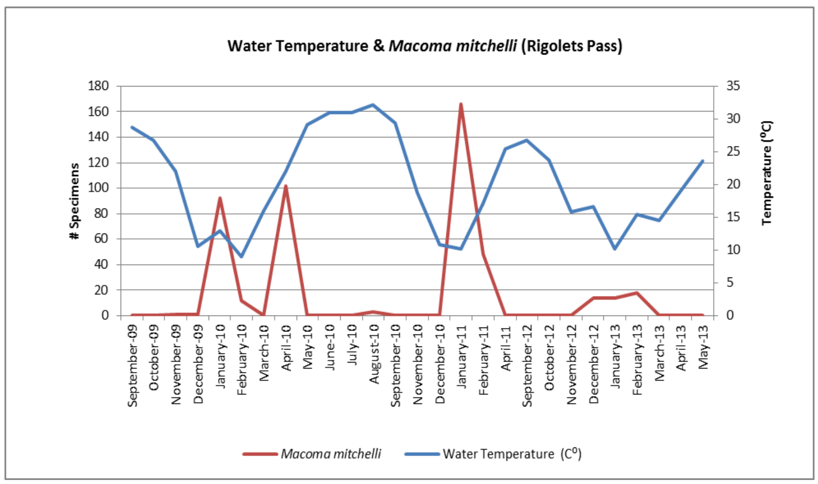
SIMPER Analysis July & August (Average Dissimilarity = 70.66)				
Species	Average Density (m^3) July	Average Density (m^3) August	Average Dissimilarity	Contribution %
Rhithropanopeus harrisii	0.53	0.90	38.71	54.78
Argulus spp.	0.19	0.14	11.09	15.69
Larval Fishes	0.00	0.13	4.22	5.97
Penaeid Shrimp	0.02	0.10	3.48	4.92
Edotia montosa	0.05	0.03	3.28	4.64
Copepod	0.01	0.09	3.15	4.46

Appendix II

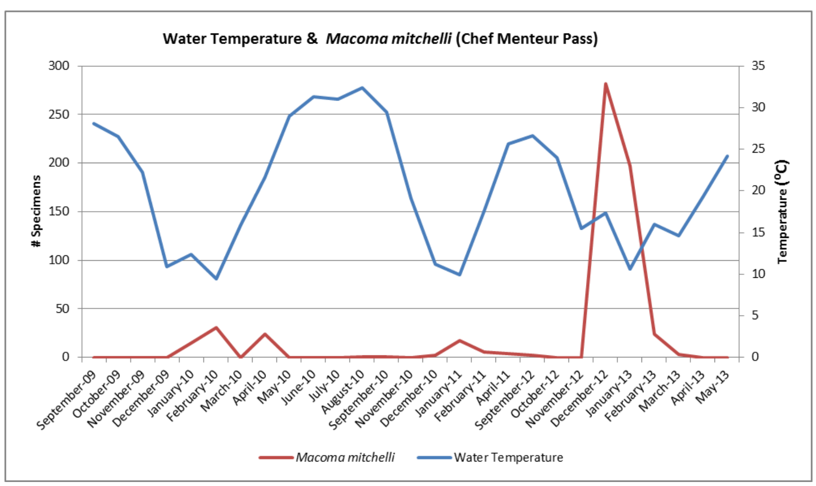
A) Scatter plot representing water temperature at the three sites from September 2009 until May 2013.



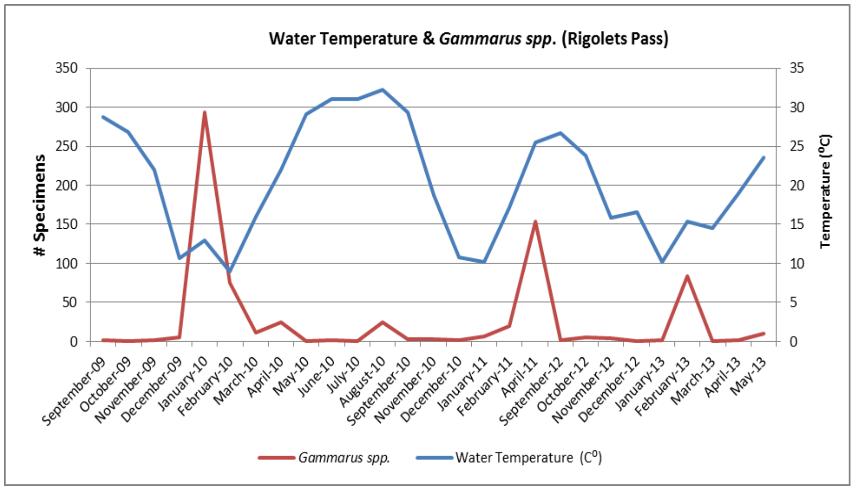
B) Scatter plot of water temperature distribution and *Macoma mitchelli* abundance at the Rigolets PassPass from September 2009 until May 2013.



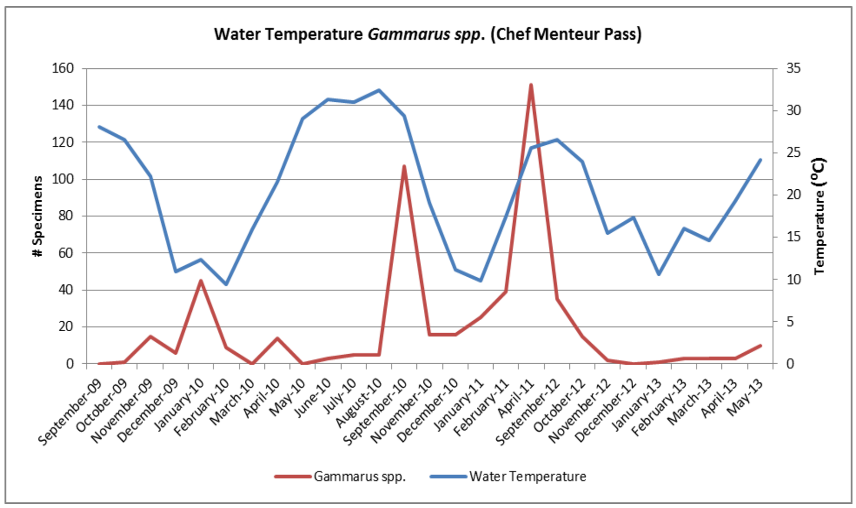
C) Scatter plot of water temperature distribution and *Macoma mitchelli* abundance at Chef Menteur Pass from September 2009 until May 2013.



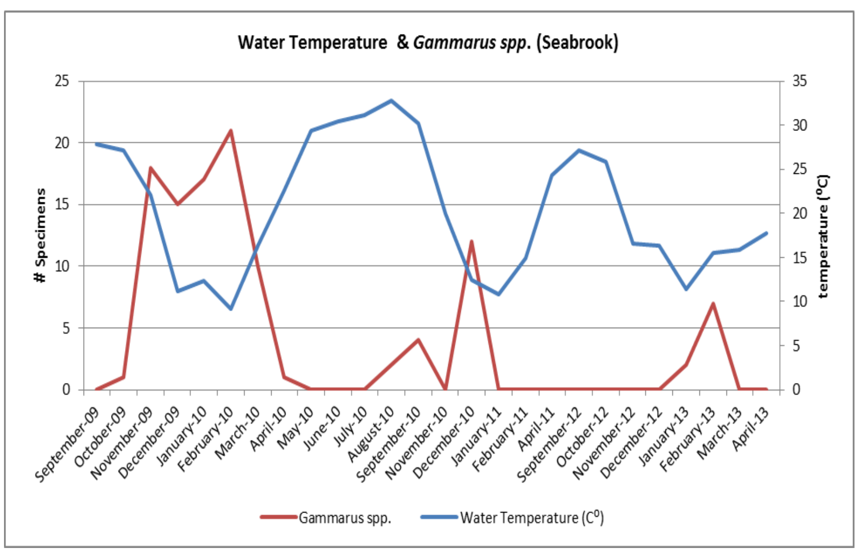
D) Scatter plot of water temperature distribution and *Gammarus spp.* abundance at the Rigolets Pass from September 2009 until May 2013.



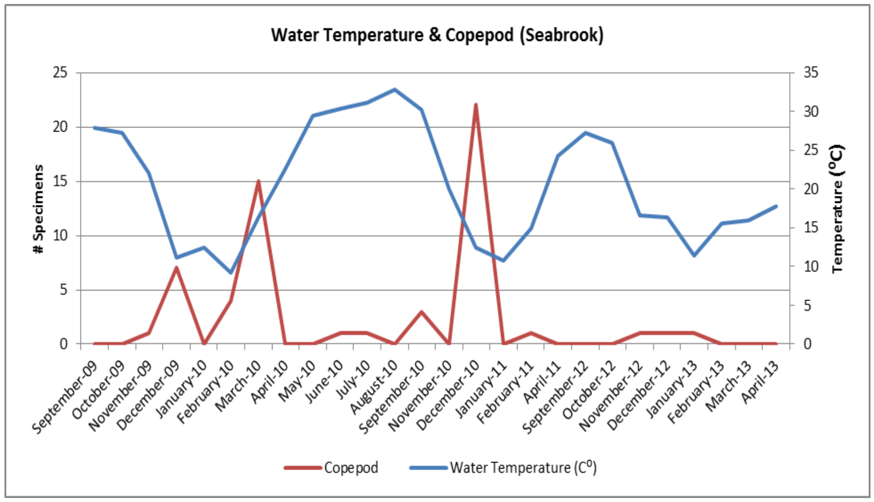
E) Scatter plot of water temperature distribution and *gammarus spp.* abundance at the Chef Menteur Pass from September 2009 until May 2013.



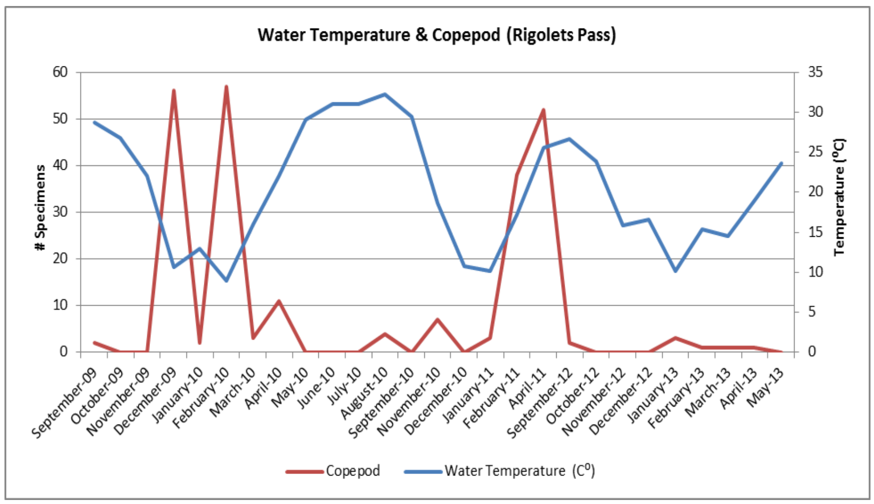
F) Scatter plot of water temperature distribution and *Gammarus spp.* abundance at seabrook from September 2009 until May 2013.



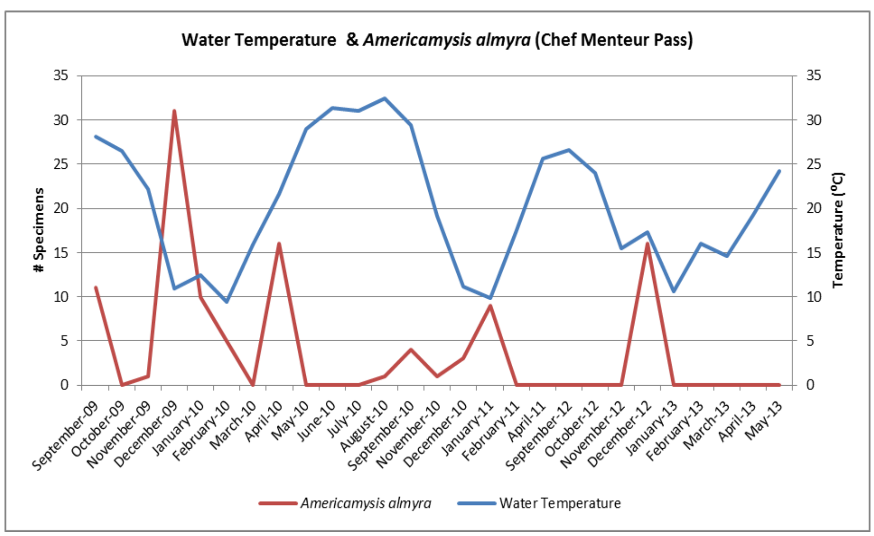
G) Scatter plot of water temperature distribution and copepod. abundance at seabrook from September 2009 until May 2013.



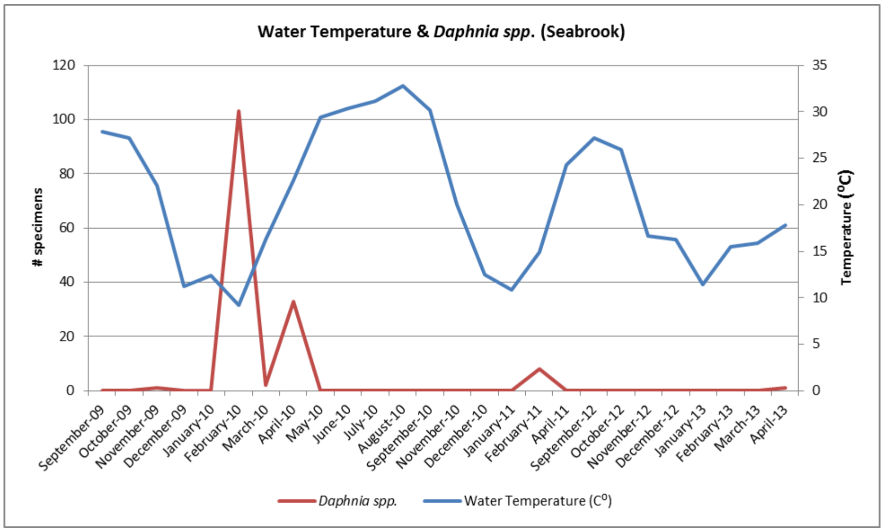
H) Scatter plot of water temperature distribution and copepod abundance at Rigolets Pass from September 2009 until May 2013.



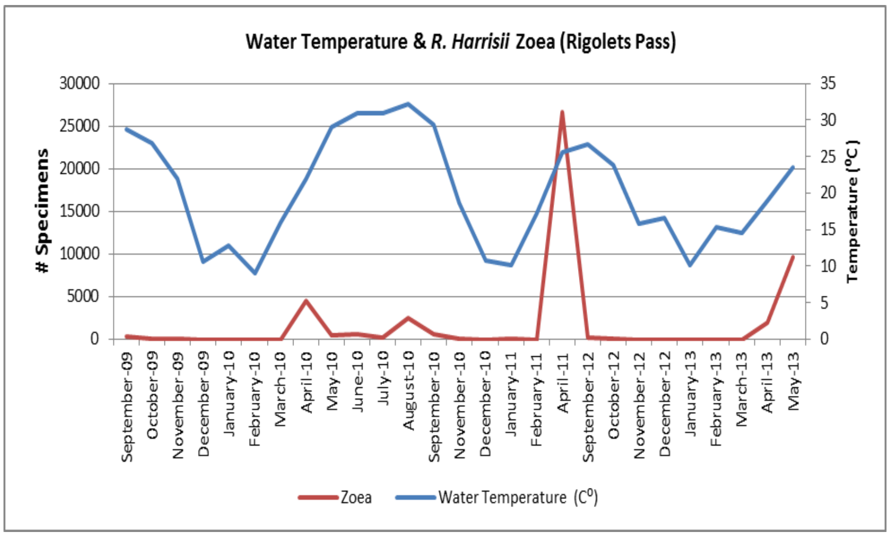
I) Scatter plot of water temperature distribution and *Americamysis almyra* abundance at Chef Menteur Pass from September 2009 until May 2013.



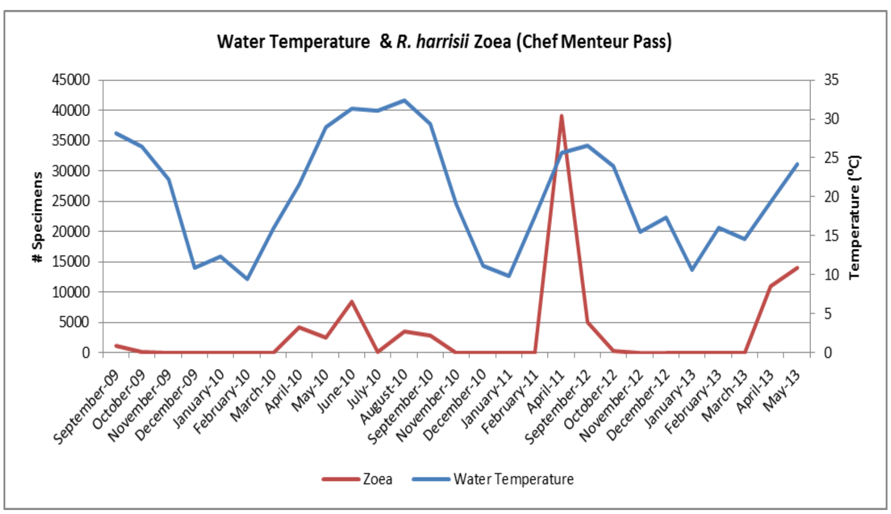
J) Scatter plot of water temperature distribution and *Daphnia spp.* abundance at seabrook from September 2009 until May 2013.



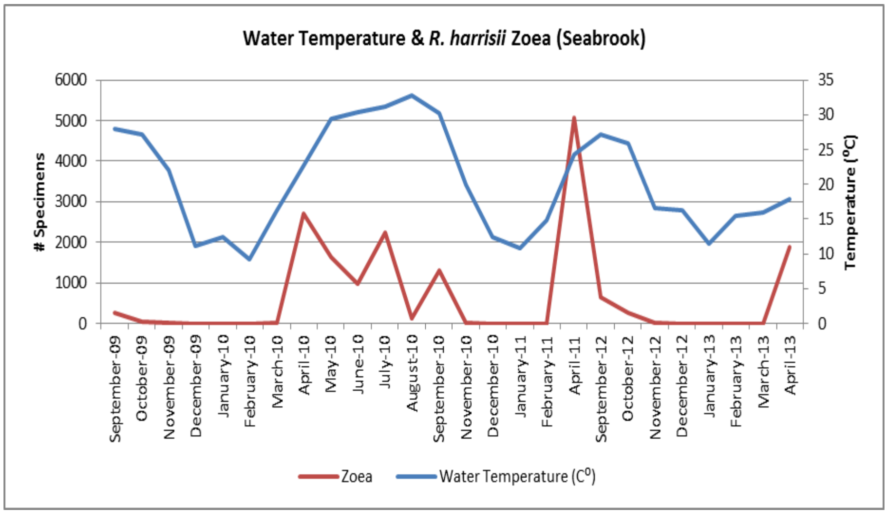
K) Scatter plot of water temperature distribution and *rhithropanopeus harrisii* zoea abundance at the Chef Menteur Pass from September 2009 until May 2013.



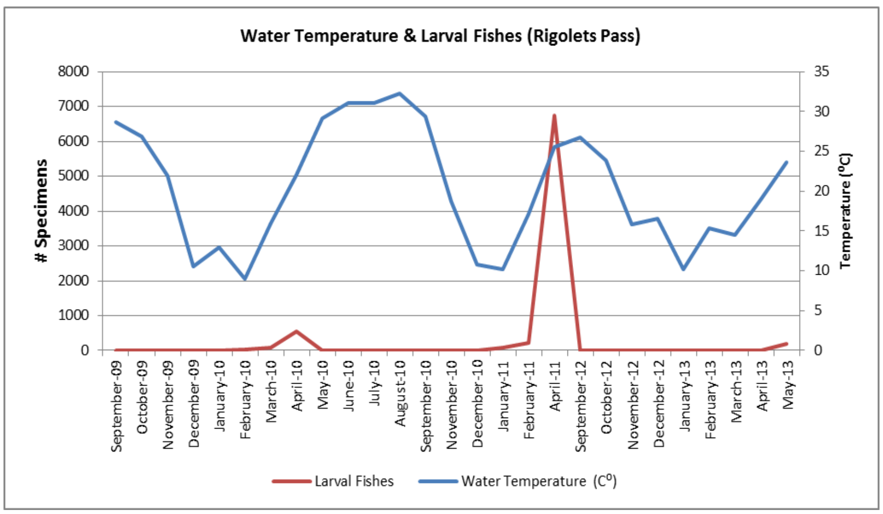
L) Scatter plot of water temperature distribution and *Rhithropanopeus harrisii* zoea abundance at the Chef Menteur Pass from September 2009 until May 2013.



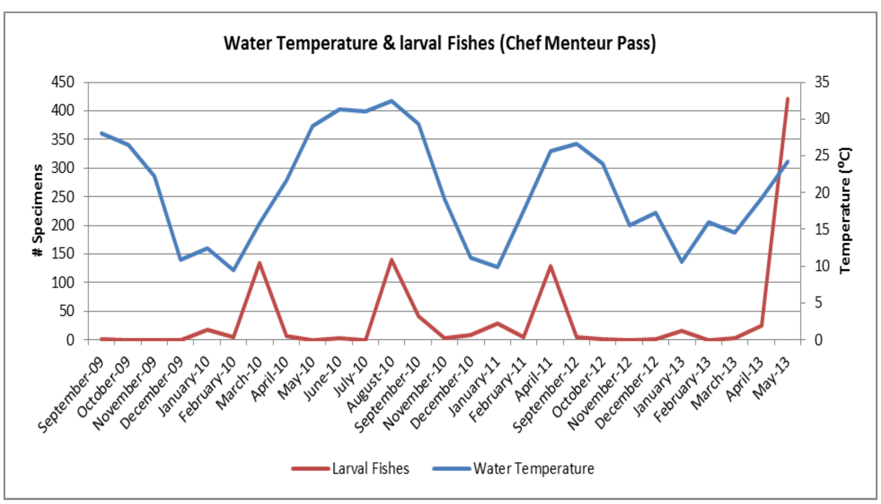
M) Scatter plot of water temperature distribution and *Rhithropanopeus harrisii* zoea abundance at the Seabrook from September 2009 until May 2013.



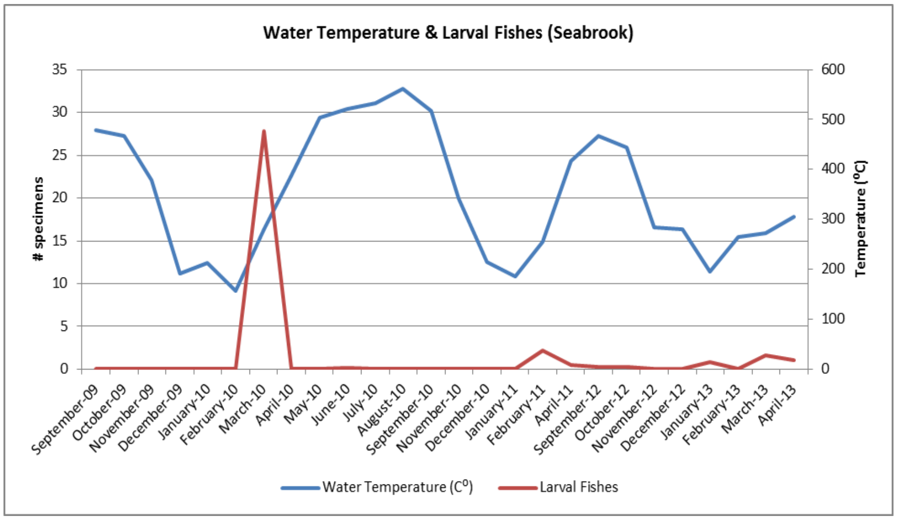
N) Scatter plot of water temperature distribution and larval fishes abundance at the Rigolets Pass from September 2009 until May 2013.



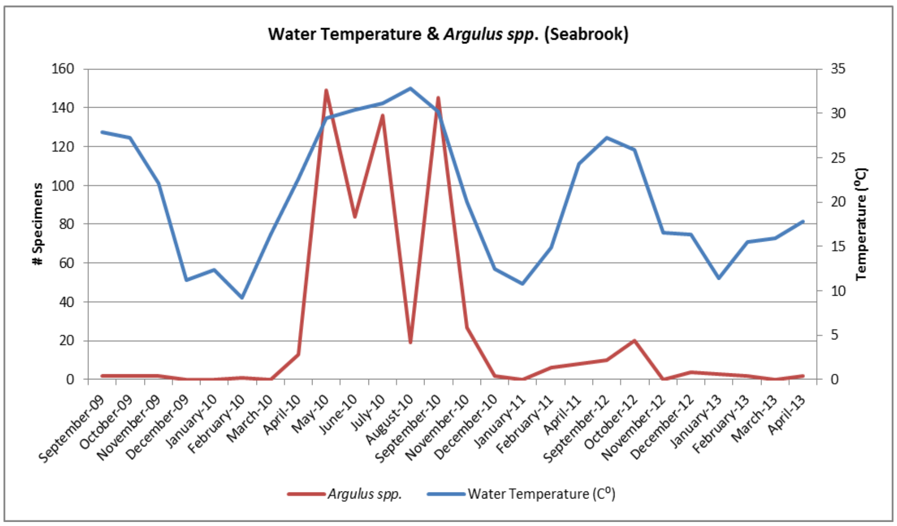
O) Scatter plot of water temperature distribution and larval fishes abundance at the Chef Menteur Pass from September 2009 until May 2013.



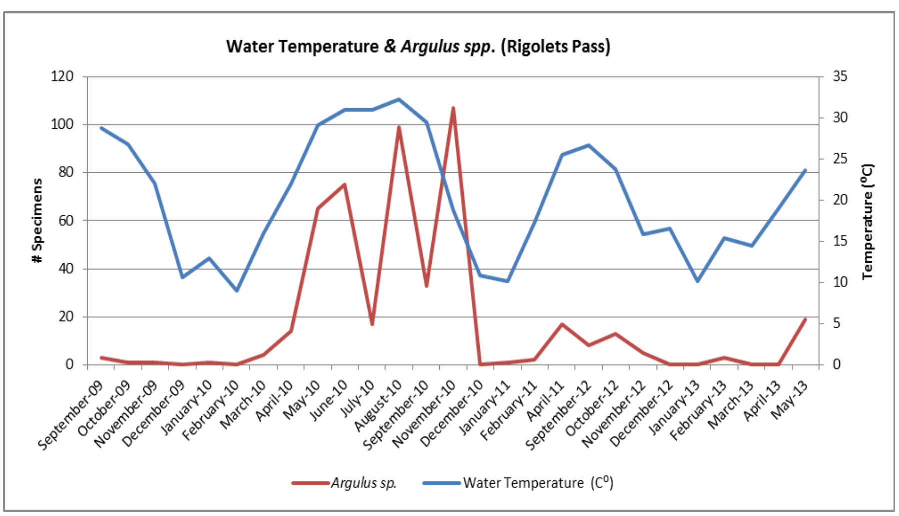
P) Scatter plot of water temperature distribution and larval fishes abundance at the Seabrook from September 2009 until May 2013.



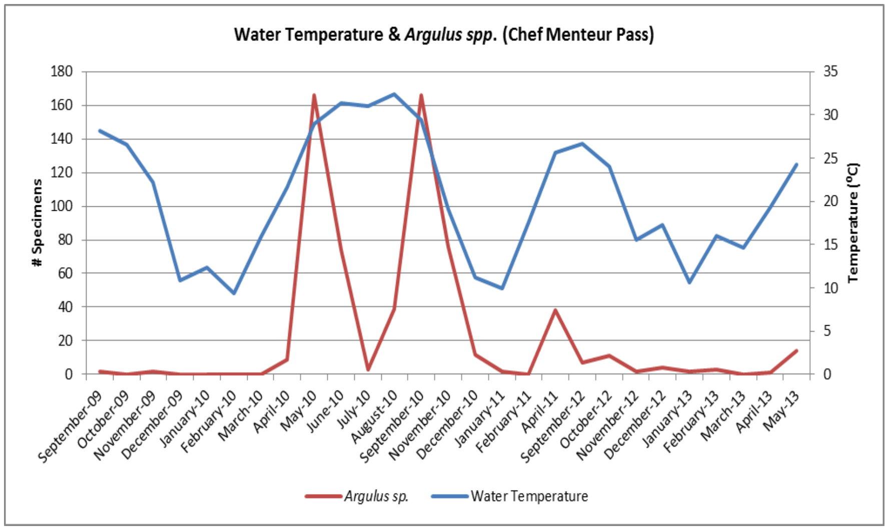
Q) Scatter plot of water temperature distribution and *Argulus spp.* abundance at seabrook from September 2009 until May 2013



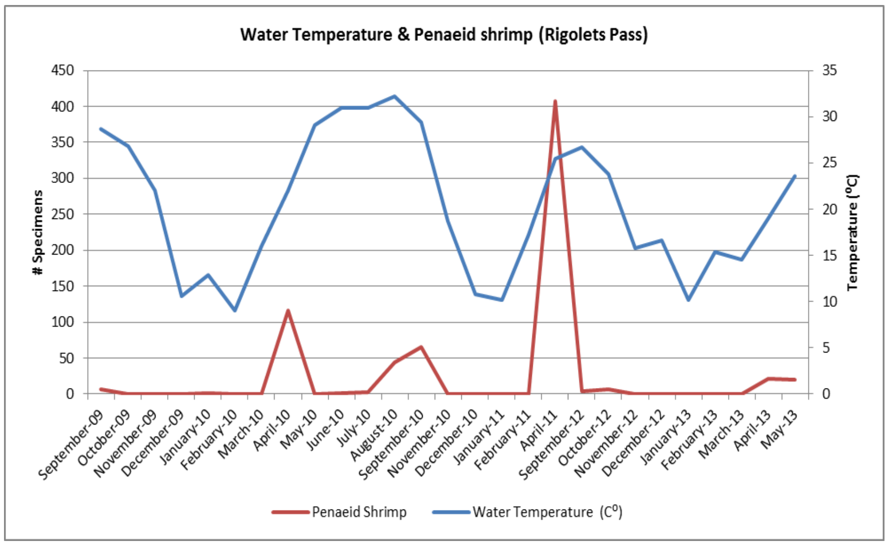
R) Scatter plot of water temperature distribution and *Argulus.* abundance at the Rigolets Pass from September 2009 until May 2013.



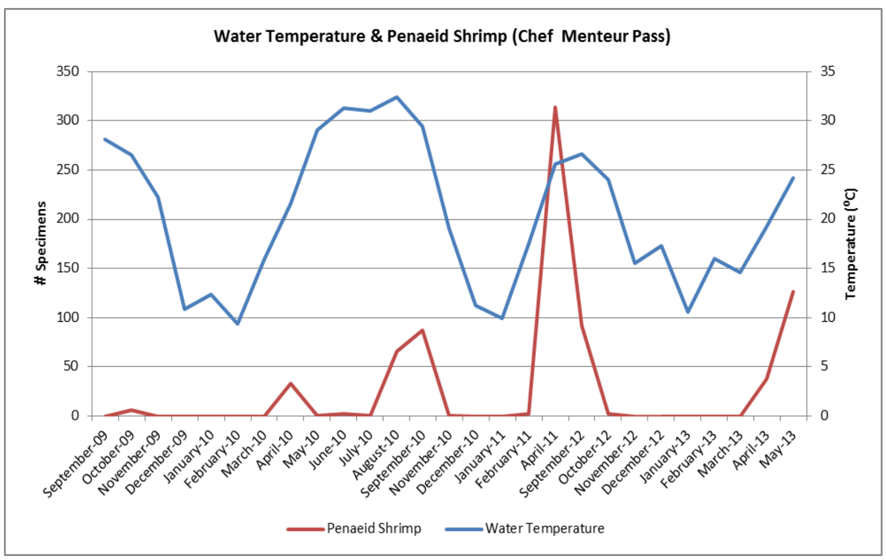
S) Scatter plot of water temperature distribution and *Argulus.* abundance at Chef Menteur Pass from September 2009 until May 2013.



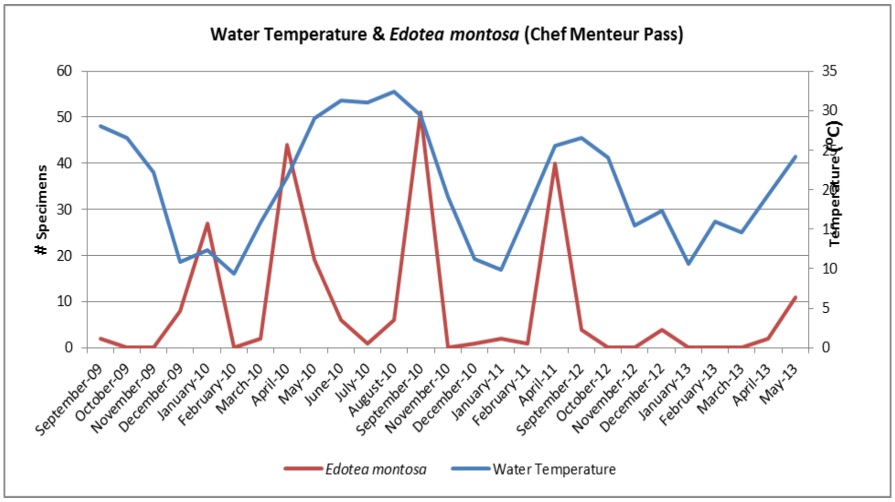
T) Scatter plot of water temperature distribution and penaeid shrimp abundance at the Rigolets Pass from September 2009 until May 2013.



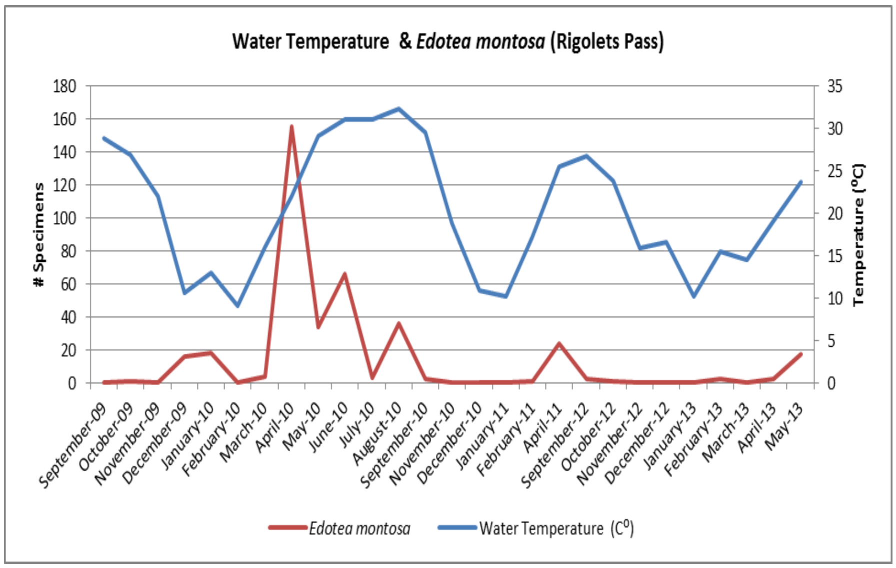
U) Scatter plot of water temperature distribution and penaeid shrimp. abundance at Chef Menteur Pass from September 2009 until May 2013.



V) Scatter plot of water temperature distribution and *Edotea montosa* abundance at Chef Menteur Pass from September 2009 until May 2013

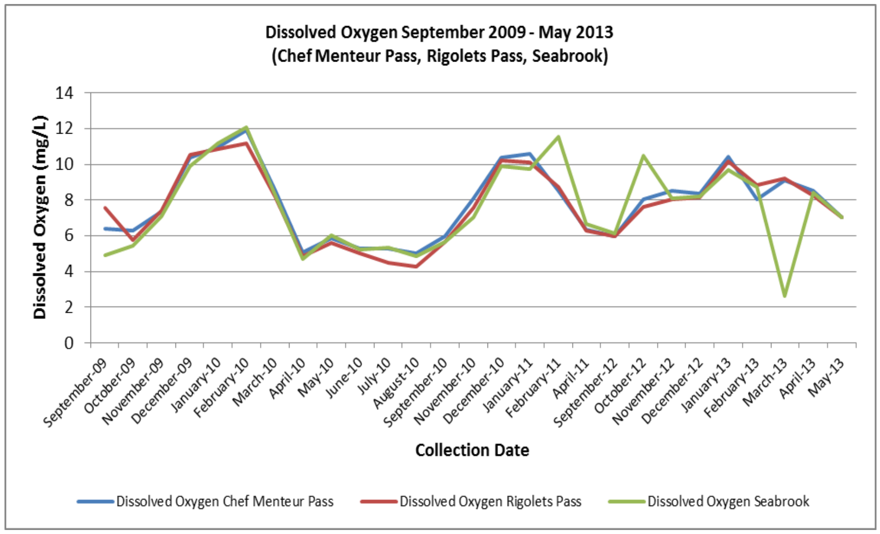


X) Scatter plot of water temperature distribution and *Edotea montosa* abundance at the Rigolets Pass from September 2009 until May 2013.

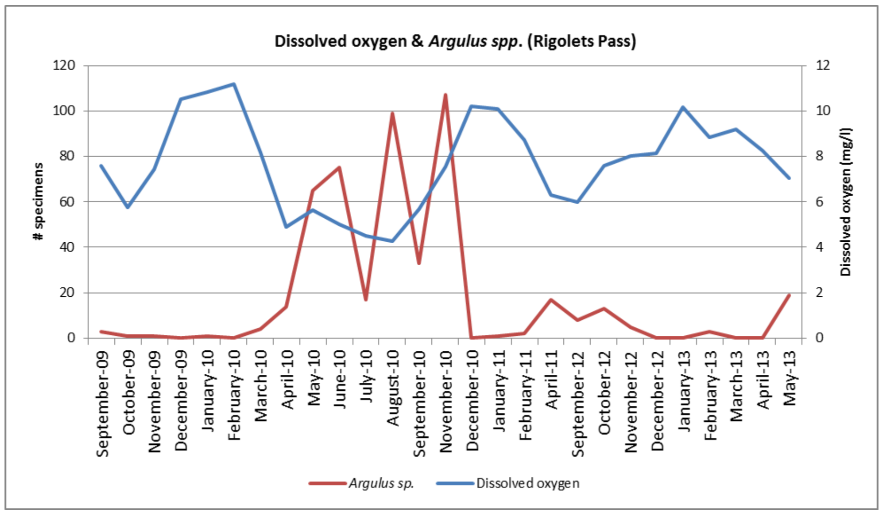


Appendix III

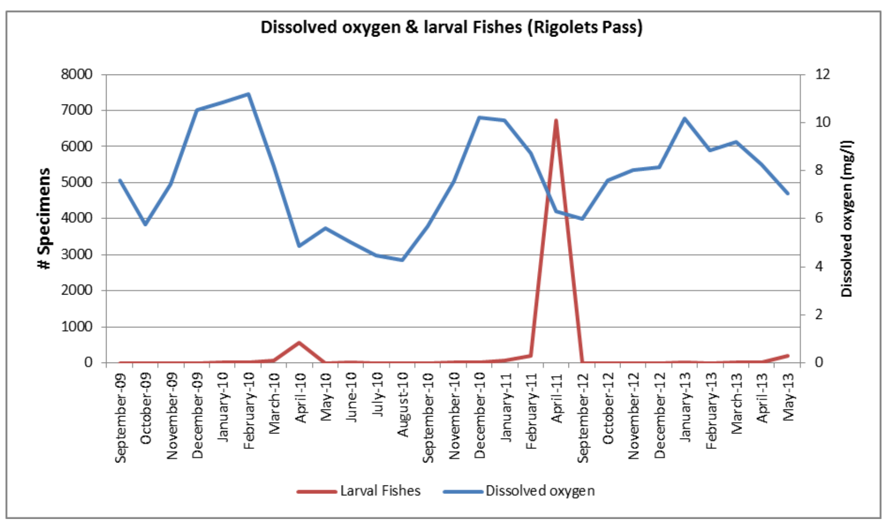
A) Scatter plot of dissolved oxygen levels at the three tidal inlets from September 2009 until May 2013



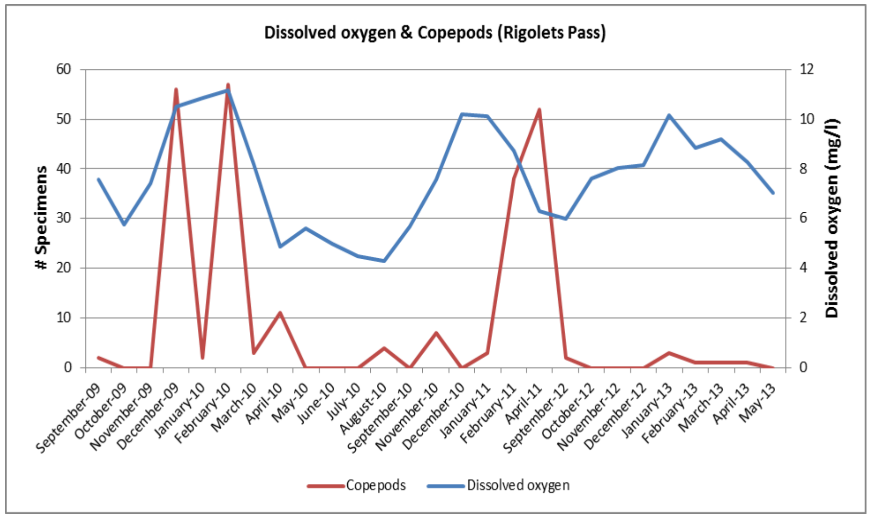
B) Scatter plot of dissolved oxygen and *Argulus spp.* abundance at the Rigolets Pass



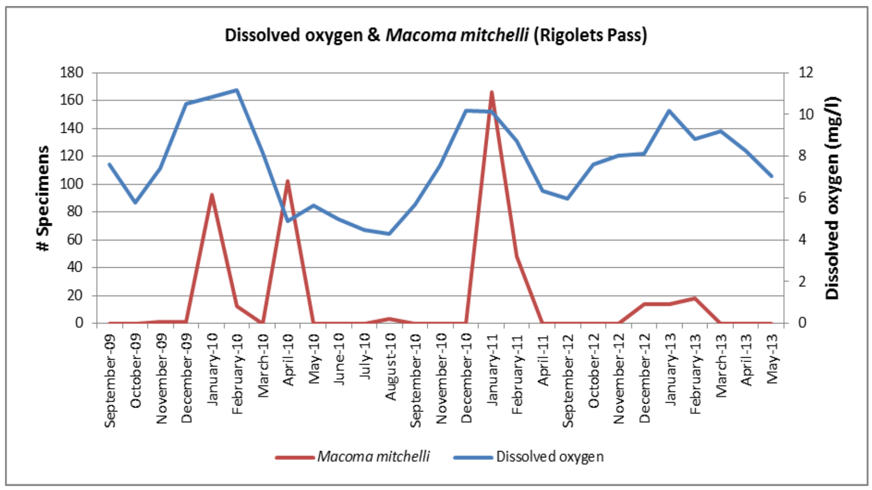
C) Scatter plot of dissolved oxygen and larval fishes abundance at the Rigolets Pass from September 2009 until May 2013



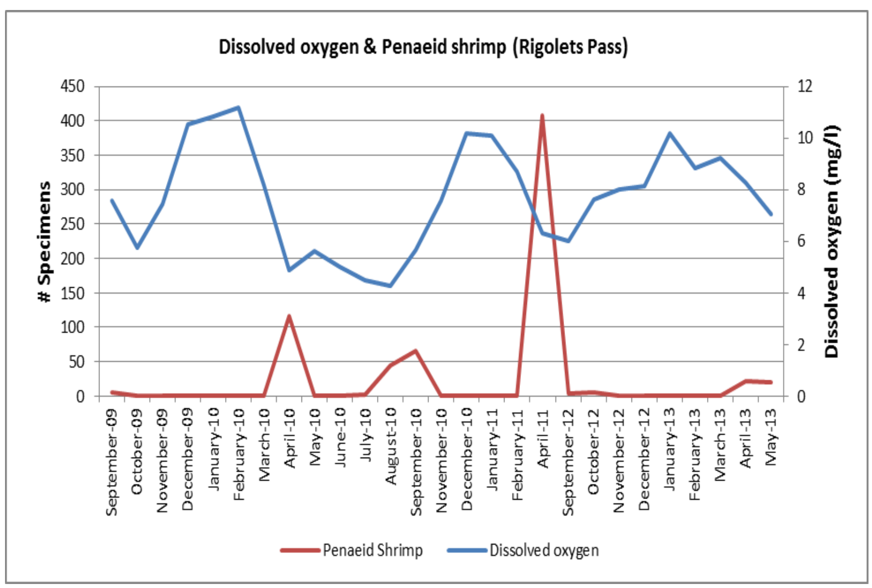
D) Scatter plot of dissolved oxygen and copepods abundance at the rigolets Pass from September 2009 until May 2013.



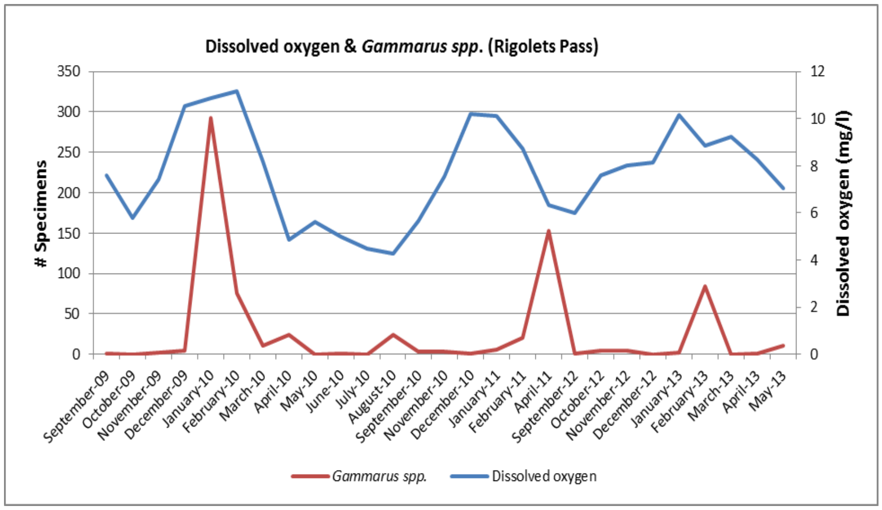
E) Scatter plot of dissolved oxygen and *Macoma mitchelli* abundance at the Rigolets Pass.



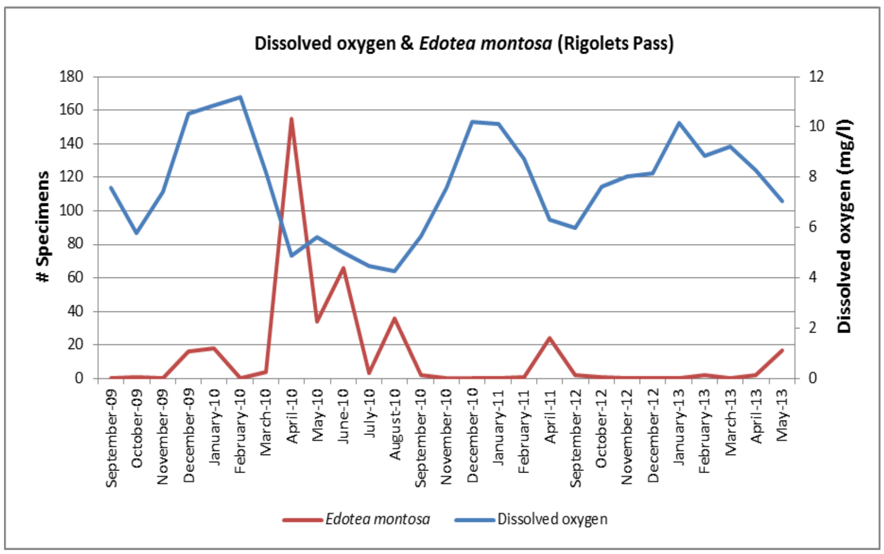
F) Scatter plot of dissolved oxygen and penaeid shrimp abundance at the Rigolets Pass.



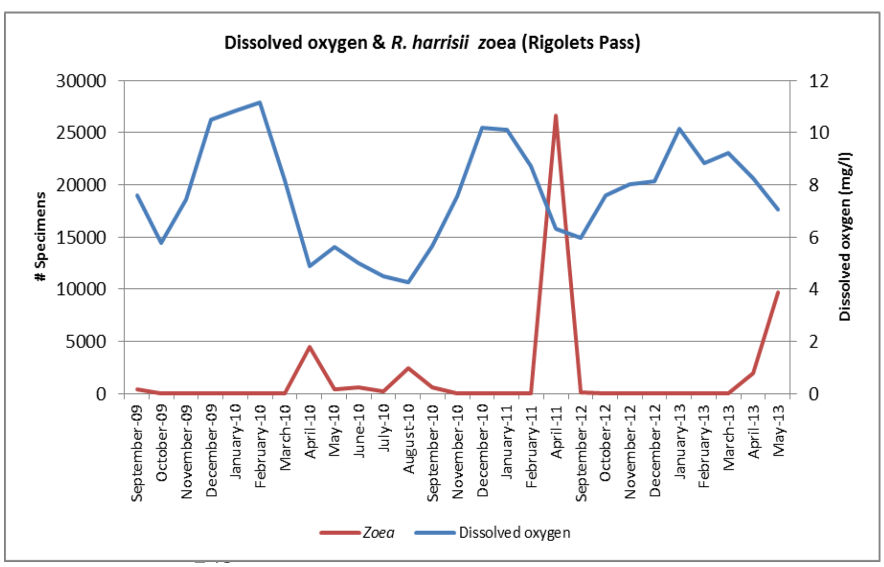
G) Scatter plot of dissolved oxygen and *Gammarus spp.* abundance at the Rigolets Pass.



H) Scatter plot of dissolved oxygen and *Edotea montosa* abundance at the Rigolets Pass.

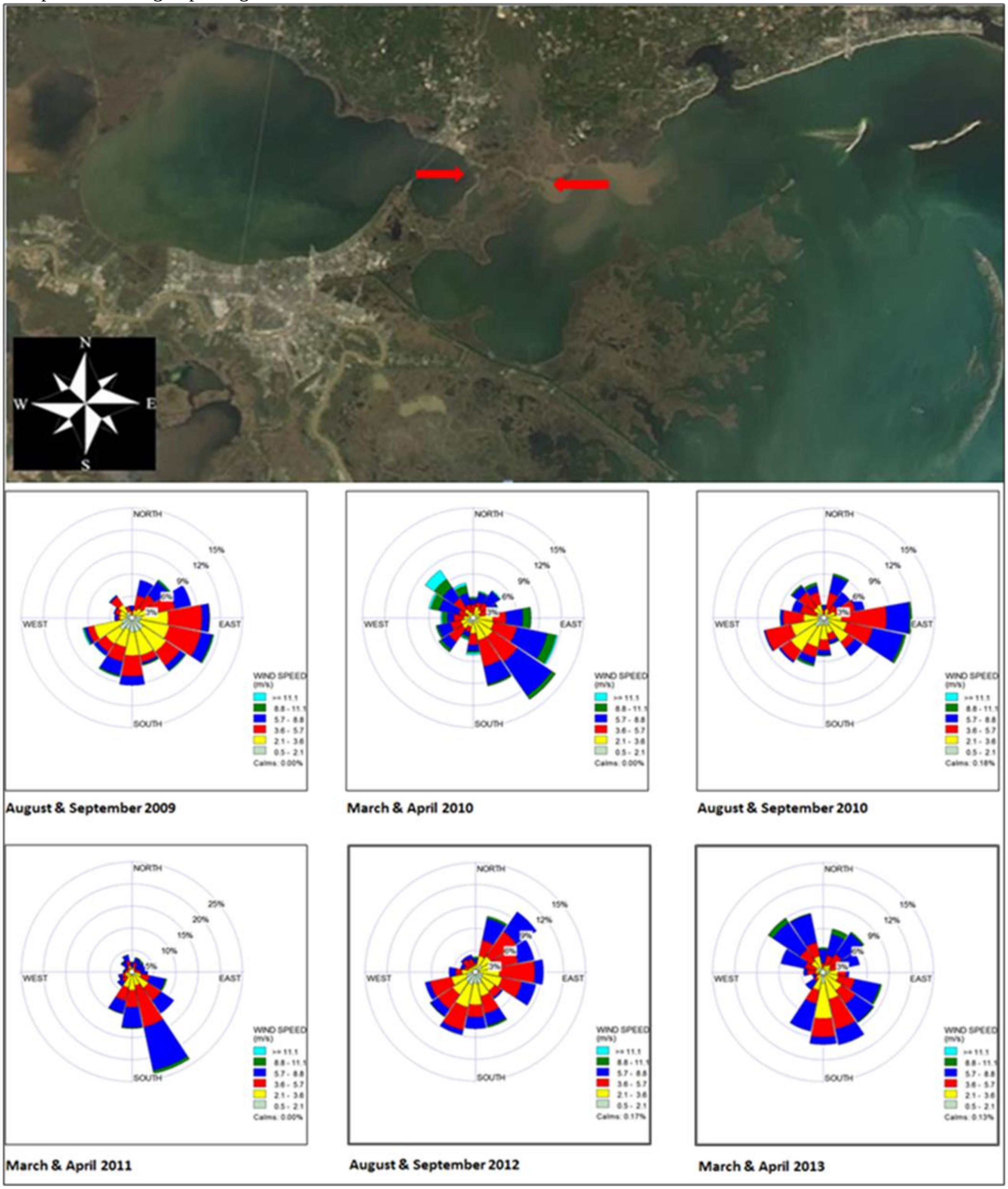


I) Scatter plot of dissolved oxygen and *Rhithropanopeus harrisii* zoea abundance at the Rigolets Pass.

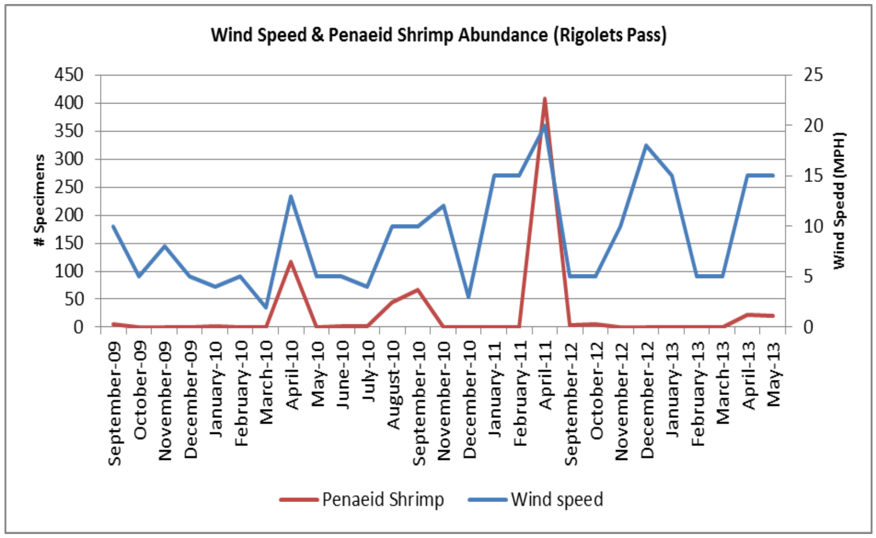


Appendix IV

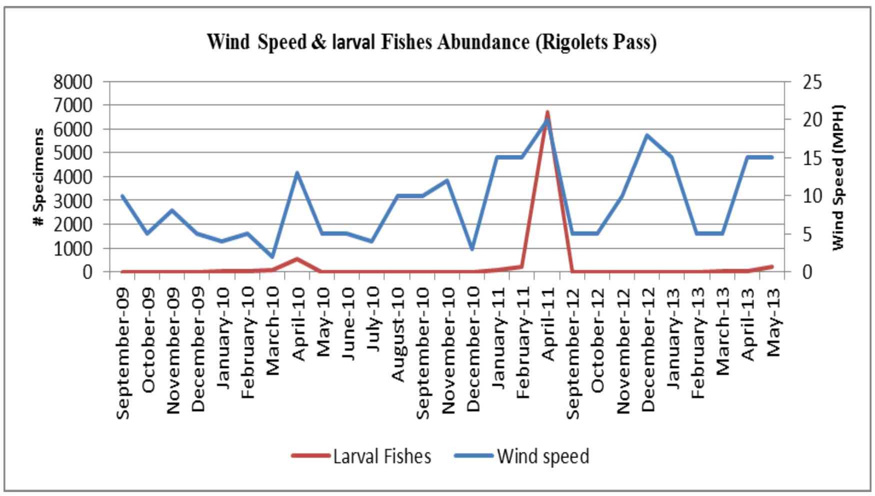
A) Map showing the location and orientation of the Rigolets Pass in association with the average wind direction and amplitude leading to pulsing events from 2009 until 2013.



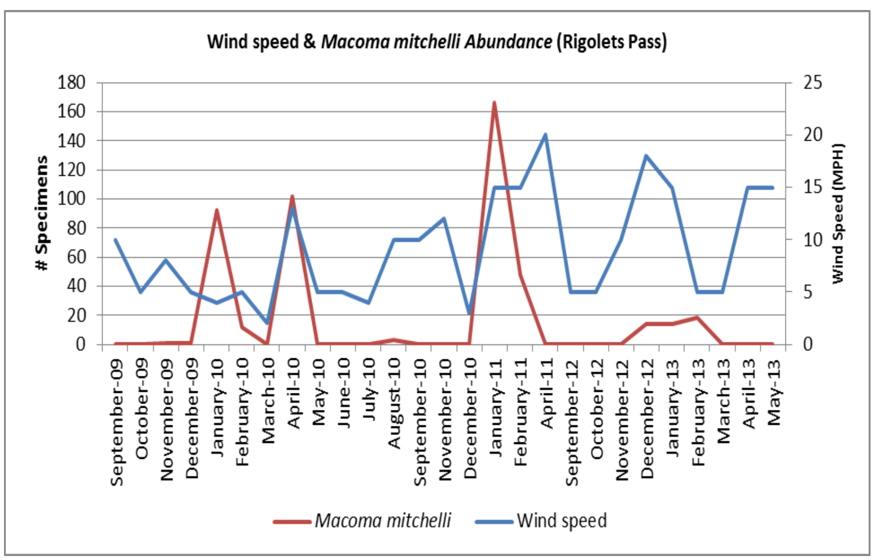
B) Scatter plot of wind speed distribution and penaeid shrimp abundance at the Rigolets Pass from September 2009 until May 2013.



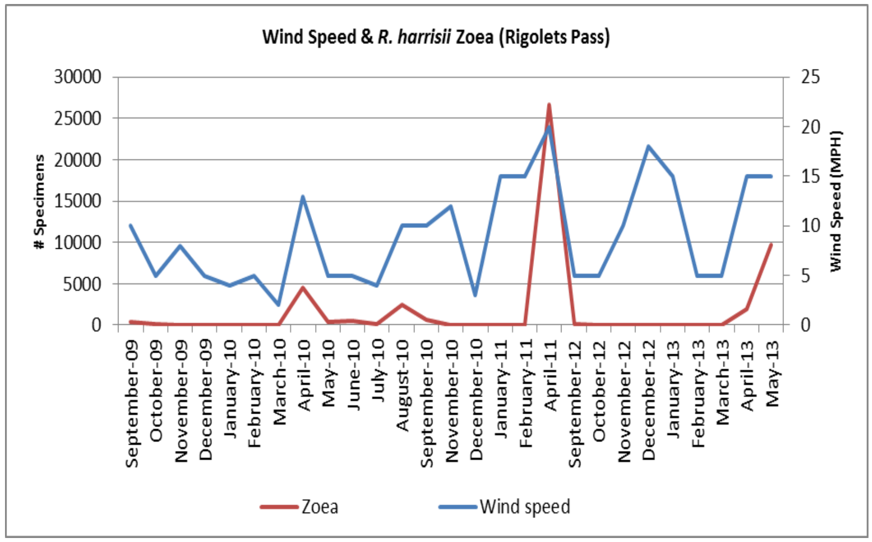
C) Scatter plot of wind speed distribution and larval fishes abundance at the Rigolets Pass from September 2009 until May 2013.



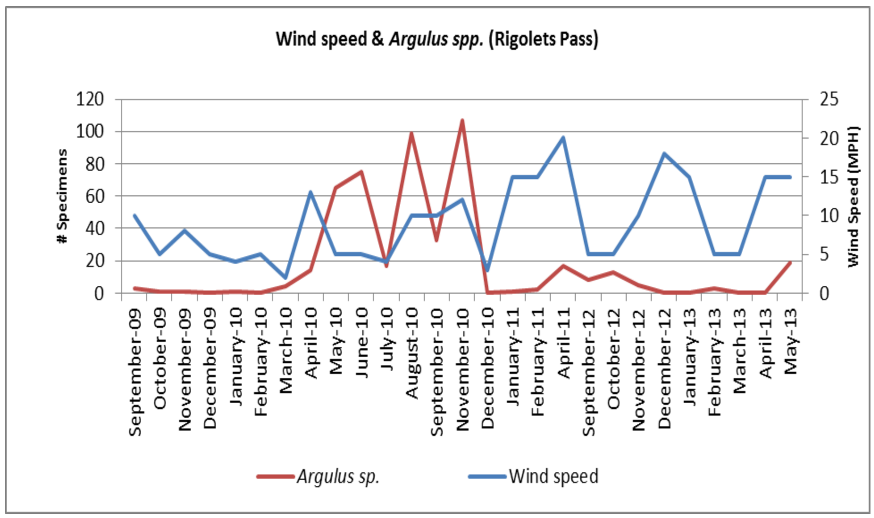
D) Scatter plot of wind speed distribution and *Macoma mitchelli* abundance at the Rigolets Pass from September 2009 until May 2013



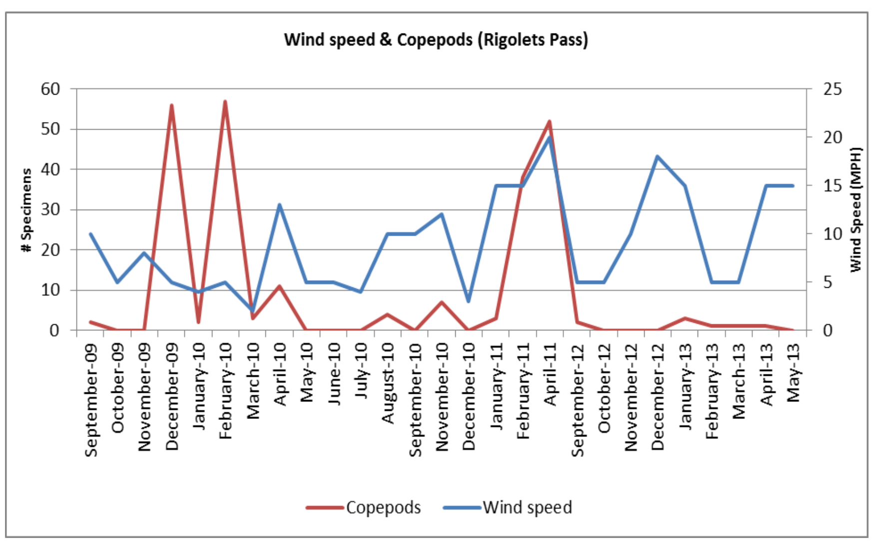
E) Scatter plot of wind speed distribution and *Rhithropanopeus harrisii* zoea abundance at the Rigolets Pass from September 2009 until May 2013.



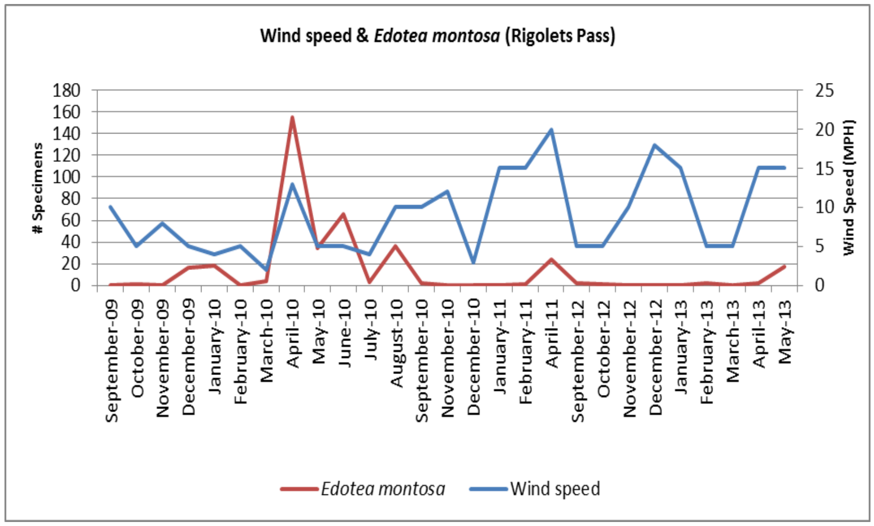
F) Scatter plot of wind speed distribution and *Argulus spp.* abundance at the Rigolets Pass from September 2009 until May 2013



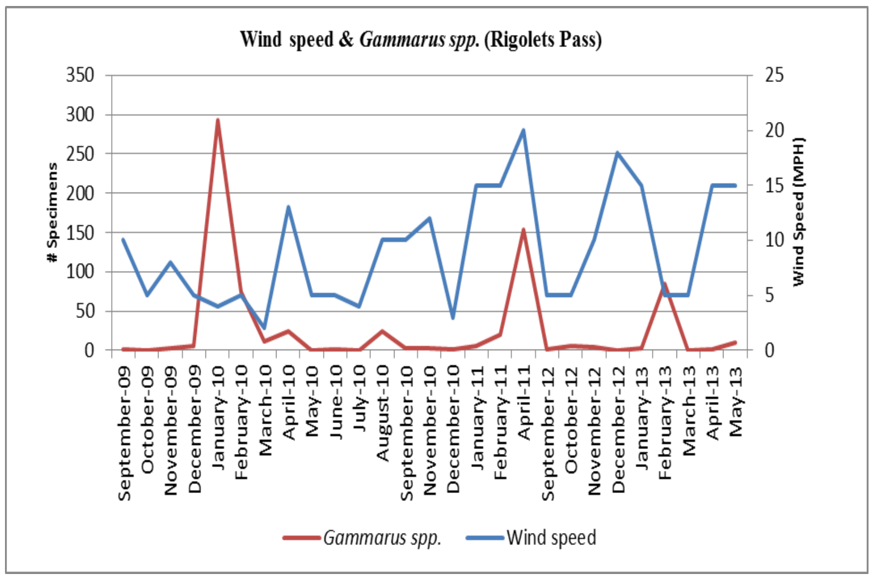
G) Scatter plot of wind speed distribution and copepods abundance at the Rigolets Pass from September 2009 until May 2013.



H) Scatter plot of wind speed distribution and *Edotea montosa* abundance at the Rigolets Pass from September 2009 until May 2013



I) Scatter plot of wind speed distribution and *Gammarus spp.* abundance at the Rigolets Pass from September 2009 until May 2013.



Appendix V

Potential impacts on the different species collected due to the possible construction and utilization of a flood control structure at the Rigolets Pass.

Species	Potential Impact	Description
Rhithropanopeus harrisii	None	Low environmental requirements. Not likely impacted
Argulus sp.	Positive	Beneficial impact. Increased parasites transmission due to greater fish density
Litopenaeus setiferus / Farfantepenaeus aztecus	Negative	Adverse impact on commercial/recreational fisheries due to interrupted recruitment
Gammarus sp.	Negative	Negative impact on communities due to habitat loss and increase wave energy
Cerapus tubularis	Positive	Low environmental requirements. Not likely impacted
Macoma mitchelli	Negative	Negative impact on communities due to potential anoxic/hypoxic episodes
Edotea montosa	None	Low environmental requirements. Not likely impacted
Copepods	Negative	Negative impact on communities due to potential anoxic/hypoxic episodes
Americamysis almyra	None	Not likely impacted
Daphnia spp.	None	Low environmental requirements. Not likely impacted
Caligus spp. -	Negative	Negatively impacted due to lower salinity regime
Lepidophthalmus louisianensis	Negative	Negatively impacted due to habitat loss.
Livoneca redmanii	None	Low environmental requirements. Not likely impacted
Polychaete worm	Negative	Negatively impacted due to potential hypoxic events and increased predation
Cystobranchus vividus	None	Low environmental requirements. Not likely impacted
Lucifer faxoni	None	Not likely impacted. Not naturally occurring in collected area

Vita

Arnaud Kerisit was born on the 13 April 1978 in Brest, and spent his childhood in Brittany, France. He received his Bachelors of Science degree in Environmental Sciences from the University of New Orleans in May 2012. He joined the Nekton Research Laboratory at the University of New Orleans in August 2012.